IN SITU THERMAL TREATMENT FOR DNAPL CONTAMINATED SITES

Sponsored by
NJDEP
&
ITRC

Regulatory Acceptance for New Solutions

October 2000 2

1. Self Introduction

•Name

•Organization

•Involvement with ITRC

Purpose of ITRC

ITRC is a state-led, national coalition of regulators and others working to

- improve state permitting processes and
- speed implementation of new environmental technologies.

ITRC works with federal agencies, industry, the public, academia, etc.

The goal is to build confidence in the use of new environmental technologies.

Goals

- Achieve better environmental protection through innovative technologies
- Reduce the technical/regulatory barriers to the use of new environmental technologies
- Build confidence about using new technologies

Other Participants

- Industry representatives
- Academia
- Public stakeholders
- Federal agencies
  - U.S. Department of Energy
  - U.S. Environmental Protection Agency
  - U.S. Department of Defense
- Host organization
  - Environmental Council of the States
- State organizations
  - Western Governors' Association
  - Southern States Energy Board

Products & Services

- Regulatory and Technical Guidelines
- Technology Overviews
- Case Studies
- Peer Exchange
- Technology Advocates
- Classroom Training Courses
- Internet-Based Training Sessions

1. Guidance Documents - Three types

•*Technical/Regulatory Guidelines* specify a standard process and common data requirements for state regulators to obtain from consultants when evaluating a new environmental technology. Technical/regulatory guidelines are formally circulated to state environmental program managers to seek their concurrence to use the guidance. By concurring with the guidance, states agree to accept performance data collected in accordance with the ITRC document as if the demonstration was performed in their own state.

•*Technology Overviews* can be status reports on emerging technologies, descriptions of state regulatory practices for treating certain types of technologies, or documents that incorporate a state regulatory perspective and input into guidance documents developed by complementary organizations.

•*Case Studies* are for benchmarking state practices in areas such as the demonstrating and approving the use of environmental technologies, as well as documenting state approaches for implementing various programs and policies.

2. A list of all ITRC documents is available in hard copy and on the ITRC Web site. All documents are (or will be) downloadable from the Web site.

Benefits to States

- Access to peers and experts in other regulatory agencies
- Shortened learning curve by obtaining advance knowledge of new and used technologies
- Cost-effective involvement in demonstrations conducted in other jurisdictions
- Sounding board for problem solving
- Information and technology transfer
- Maximize limited resources
- Personal and professional development

Benefits to Industry

- Forum conducive to advancing technology and solutions
- Insight into the regulatory world
- Access to multiple state entities
- Opportunity for broader review of technology
- Unique and cost-effective approach to demonstration and deployment of new technology
- Mechanism to identify and integrate regulatory performance expectations amongst states

Presentations

Continuing DNAPL mobility at MGP sites
Gardiner Cross,
New York State, Department of Environmental Conservation

Steam Enhanced Extraction (SEE)
Jim Cummings, Technology Innovation Office, USEPA

Three/Six Phase Electrical Resistive Heating
Jim Cummings, Technology Innovation Office, USEPA

Thermal Conductive Heating
John LaChance, Terratherm

Policy Framework for Considering NAPL Remedial Alternatives
Jim Cummings, Technology Innovation Office, USEPA

RIMS Update

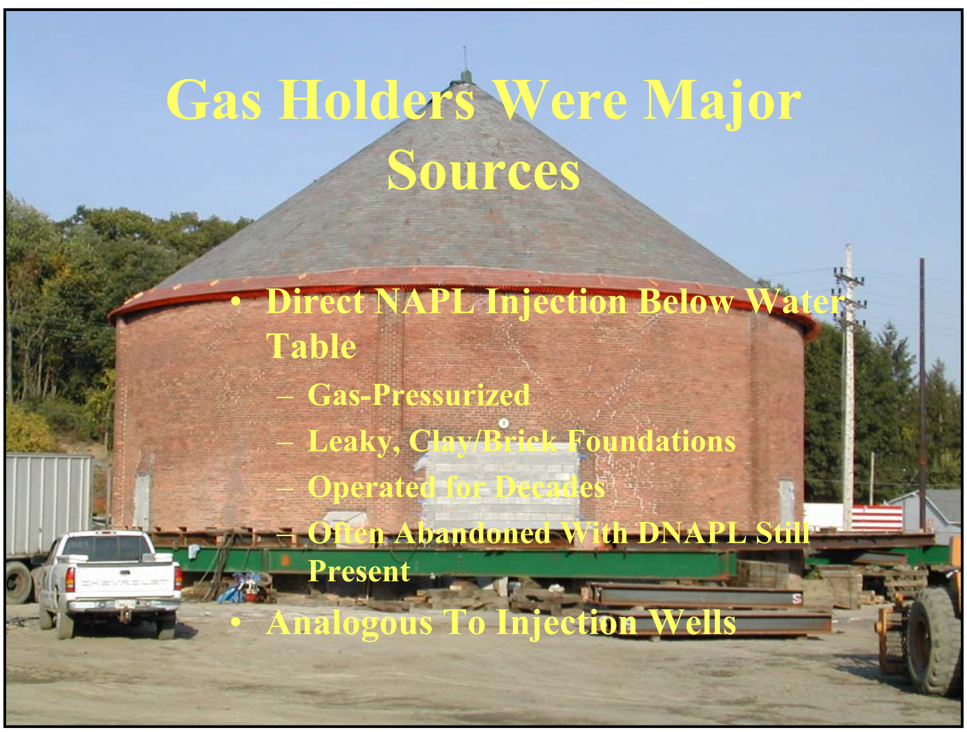
Continuing DNAPL Mobility at MGP Sites: A New York Perspective

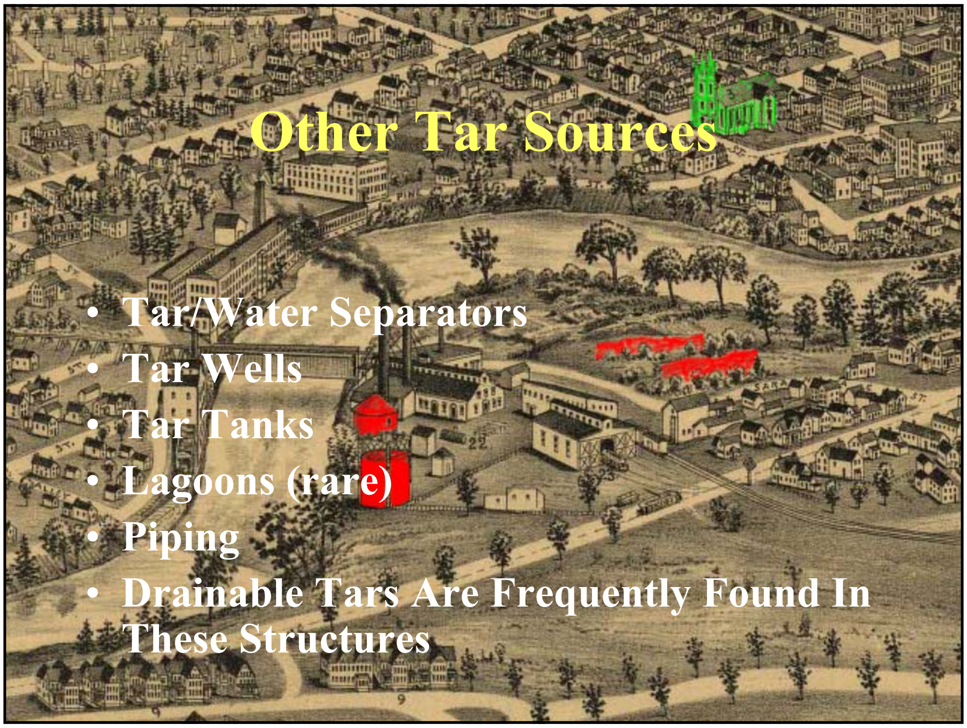
- Gardiner Cross
- New York State Department of Environmental Conservation

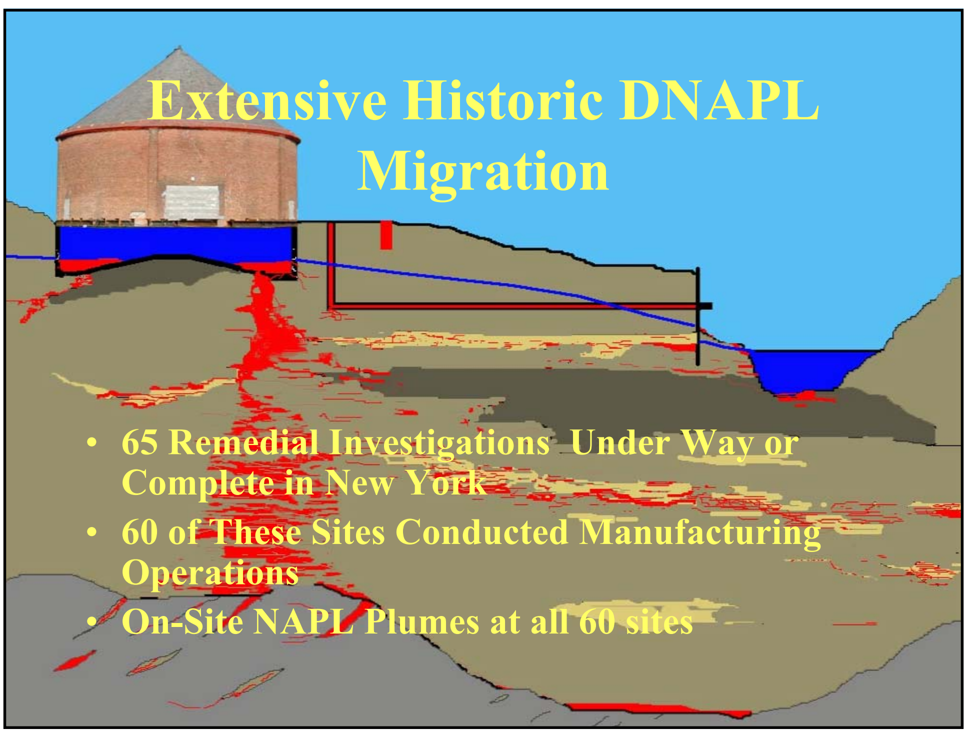
Over 300 MGP Sites Thought To Exist In New York State

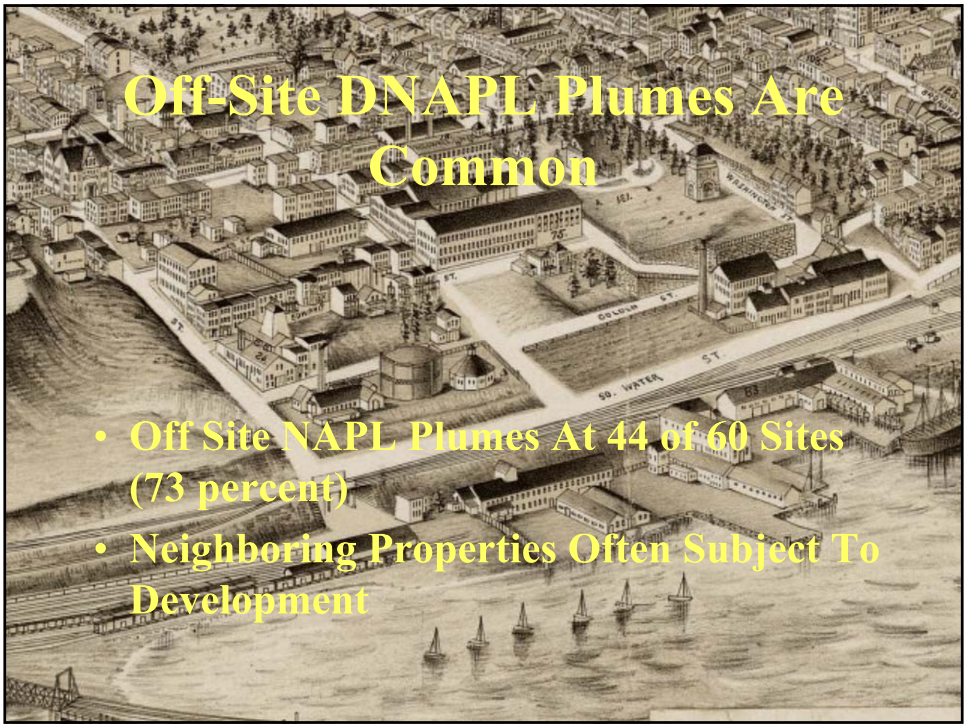
- Typically Located In Older Downtown Areas
- Most Areas Have Public Water
- Typically Located Near Surface Water Bodies

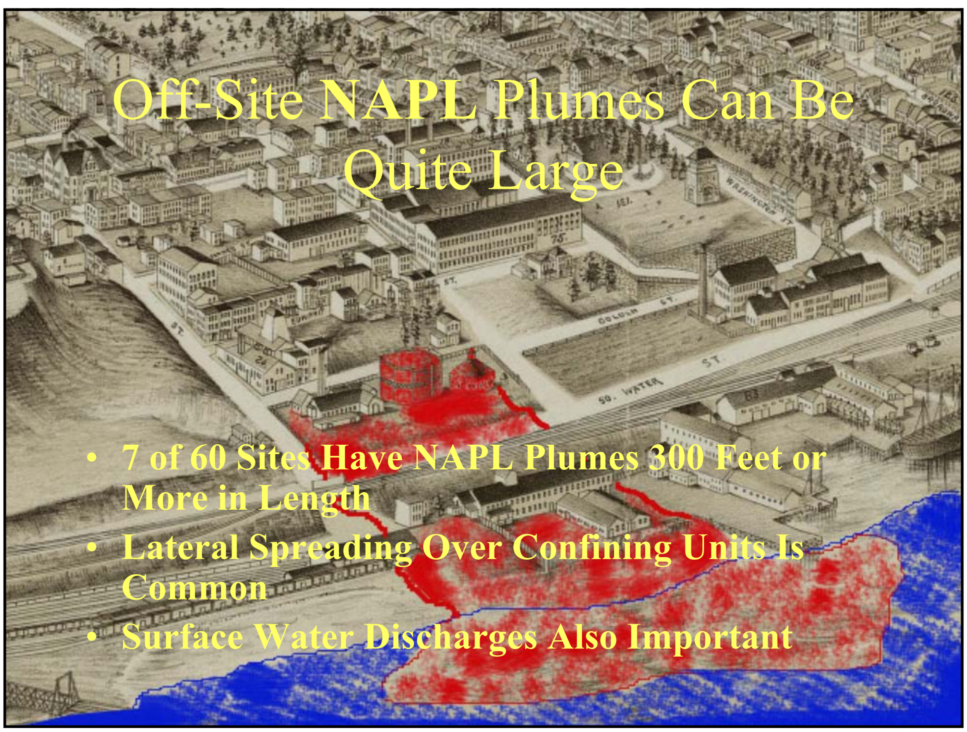

Gas Holders Were The Original Targets
• "Coal Tar" thought To Be Largely Immobile
– Viscosity
• Analogous to Petroleum Spills

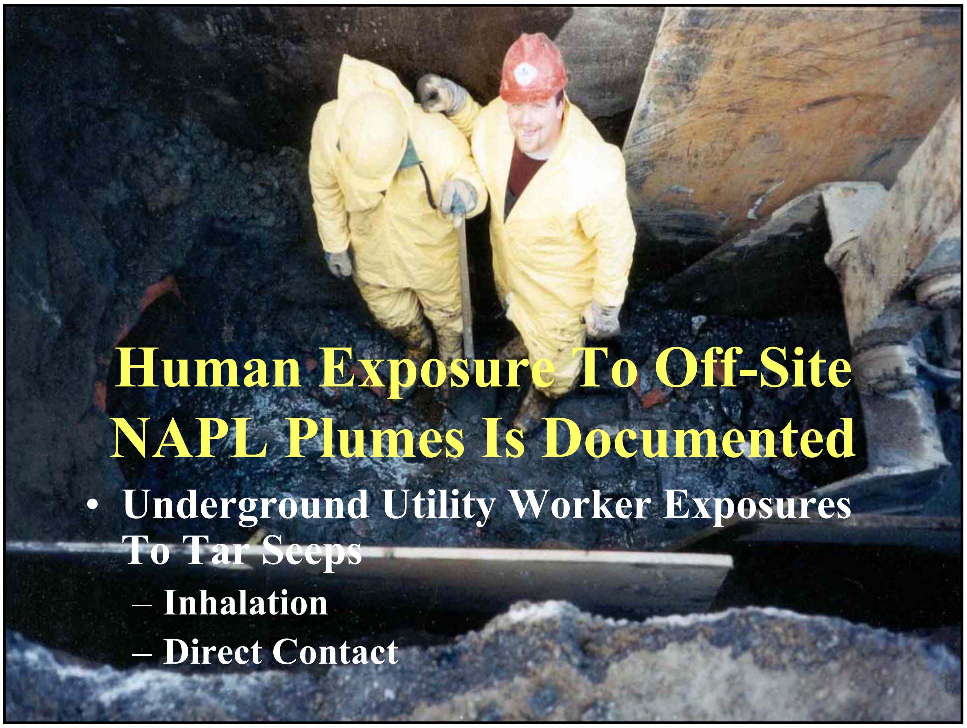

Gas Holders Were Major Sources
• Direct NAPL Injection Below Water Table
– Gas-Pressurized
– Leaky, Clay/Brick Foundations
– Operated for Decades
– Often Abandoned With DNAPL Still Present
• Analogous To Injection Wells

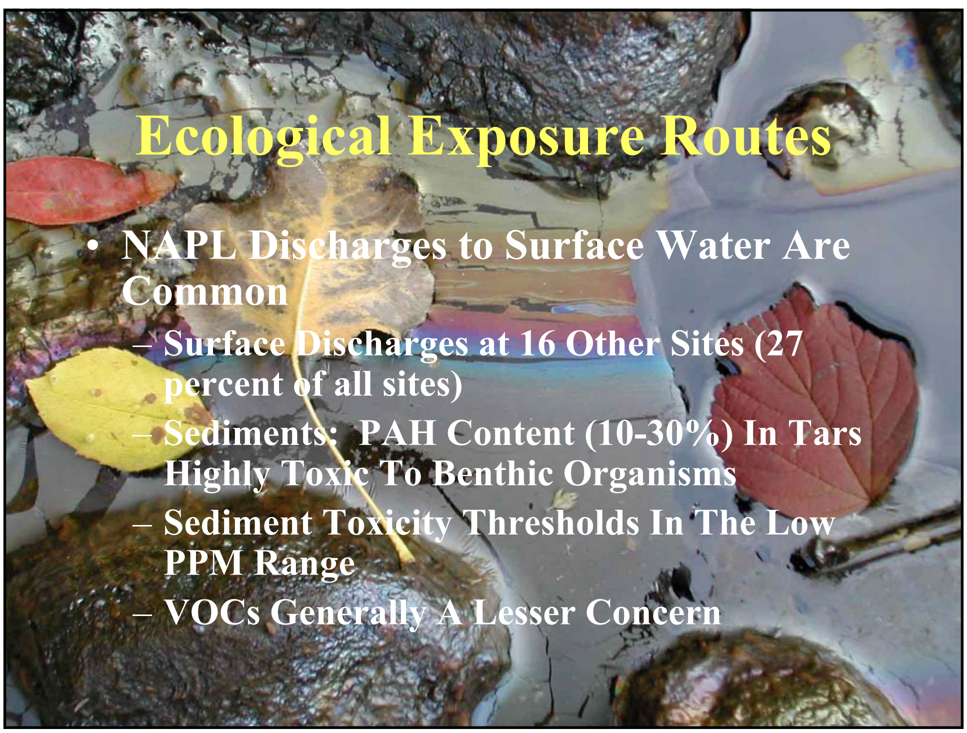

Other Tar Sources
• Tar/Water Separators
• Tar Wells
• Tar Tanks
• Lagoons (rare)
• Piping
• Drainable Tars Are Frequently Found In These Structures


Extensive Historic DNAPL Migration
• 65 Remedial Investigations Under Way or Complete in New York
• 60 of These Sites Conducted Manufacturing Operations
• On-Site NAPL Plumes at all 60 sites


Off-Site DNAPL Plumes Are Common
• Off Site NAPL Plumes At 44 of 60 Sites (73 percent)
• Neighboring Properties Often Subject To Development

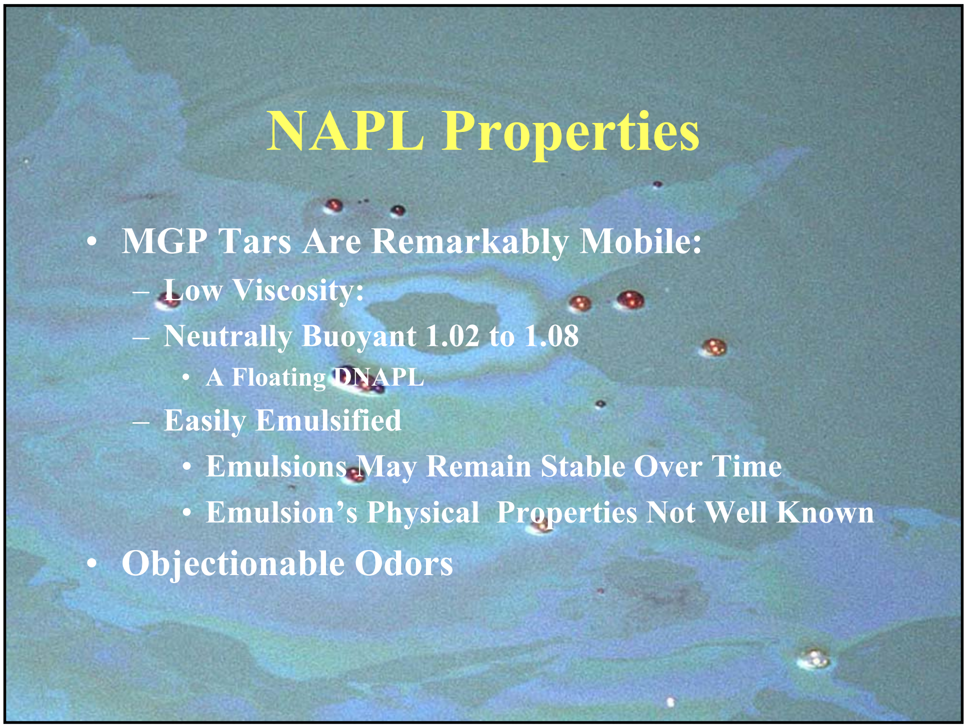

Off-Site NAPL Plumes Can Be Quite Large
• 7 of 60 Sites Have NAPL Plumes 300 Feet or More in Length
• Lateral Spreading Over Confining Units Is Common
• Surface Water Discharges Also Important


Human Exposure To Off-Site NAPL Plumes Is Documented
• Underground Utility Worker Exposures To Tar Seeps
– Inhalation
– Direct Contact

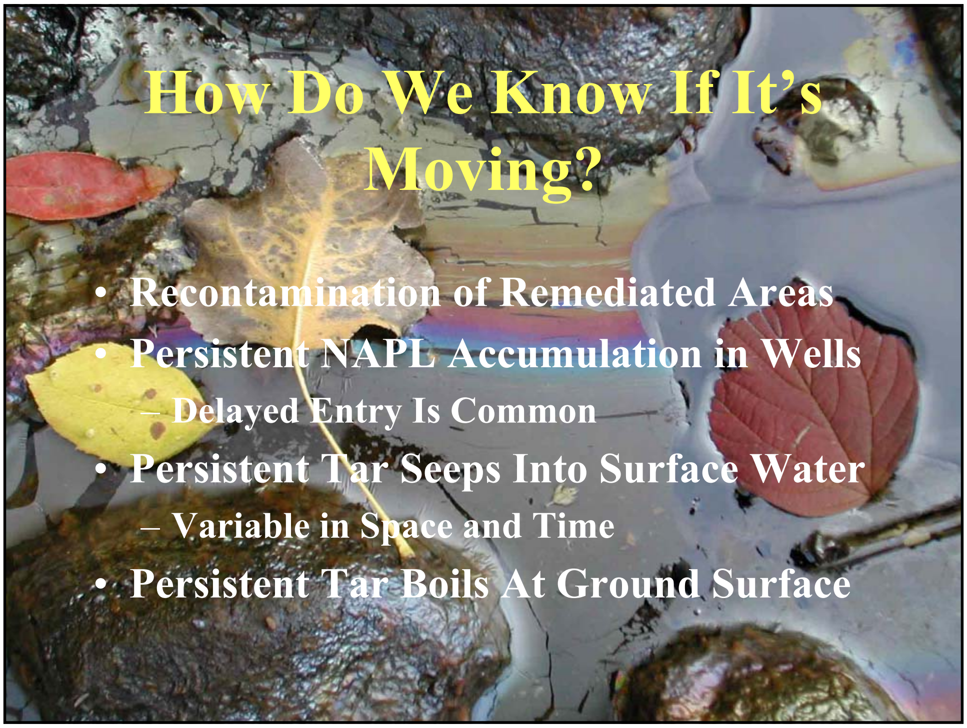

Ecological Exposure Routes
• NAPL Discharges to Surface Water Are Common
– Surface Discharges at 16 Other Sites (27 percent of all sites)
– Sediments: PAH Content (10-30%) In Tars Highly Toxic To Benthic Organisms
– Sediment Toxicity Thresholds In The Low PPM Range
– VOCs Generally A Lesser Concern

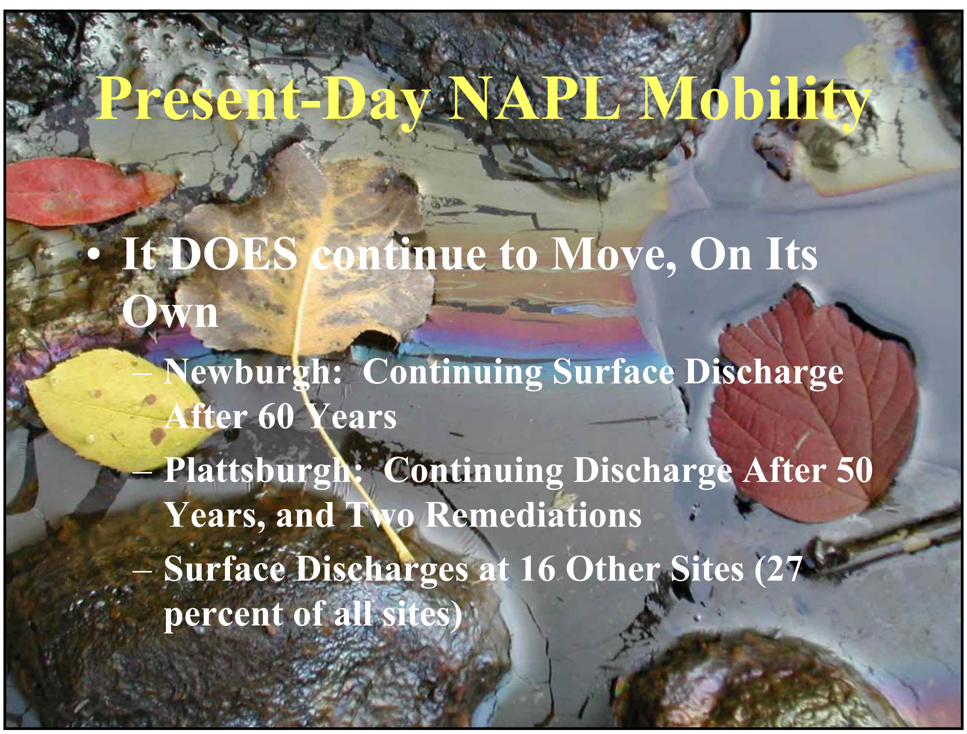

Present-Day NAPL Mobility
• But My Calculation Says It Can't Move…
– Field Observations Trump Calculations
– This Isn't Really Coal Tar
– Emulsions

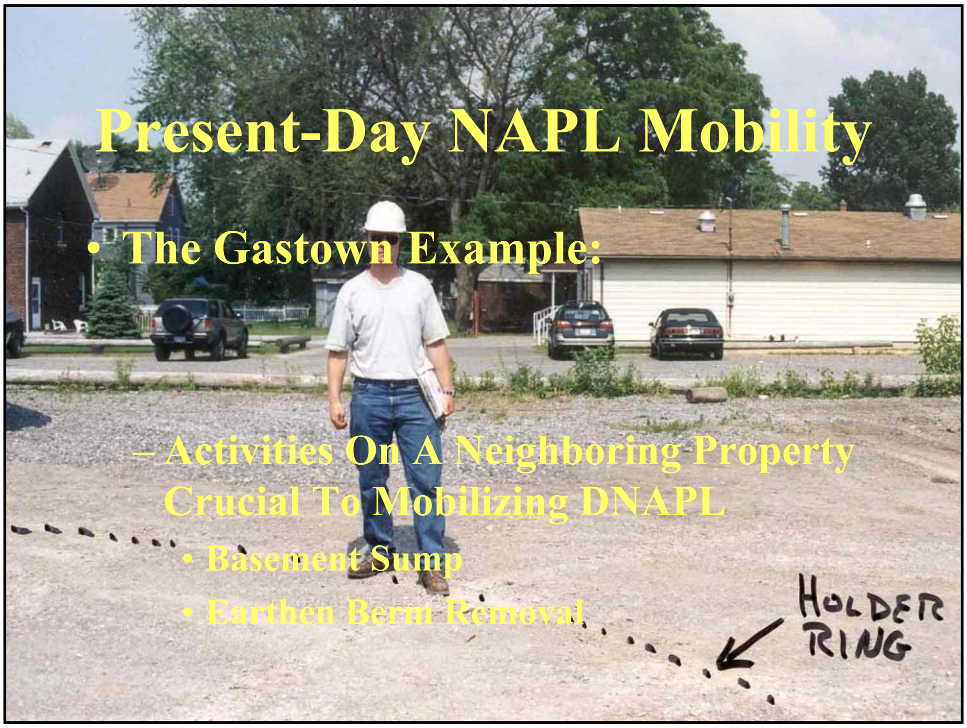

Coal Tar is a Misnomer
• Most New York State MGPs Used Carburetted Water Gas (CWG) Processes
– CWG Tars Were Primarily Derived From Petroleum, Not Coal
– CWG Tars Were Not "Tarry"


NAPL Properties
• MGP Tars Are Remarkably Mobile:
– Low Viscosity:
– Neutrally Buoyant 1.02 to 1.08
• A Floating DNAPL
– Easily Emulsified
• Emulsions May Remain Stable Over Time
• Emulsion's Physical Properties Not Well Known
• Objectionable Odors

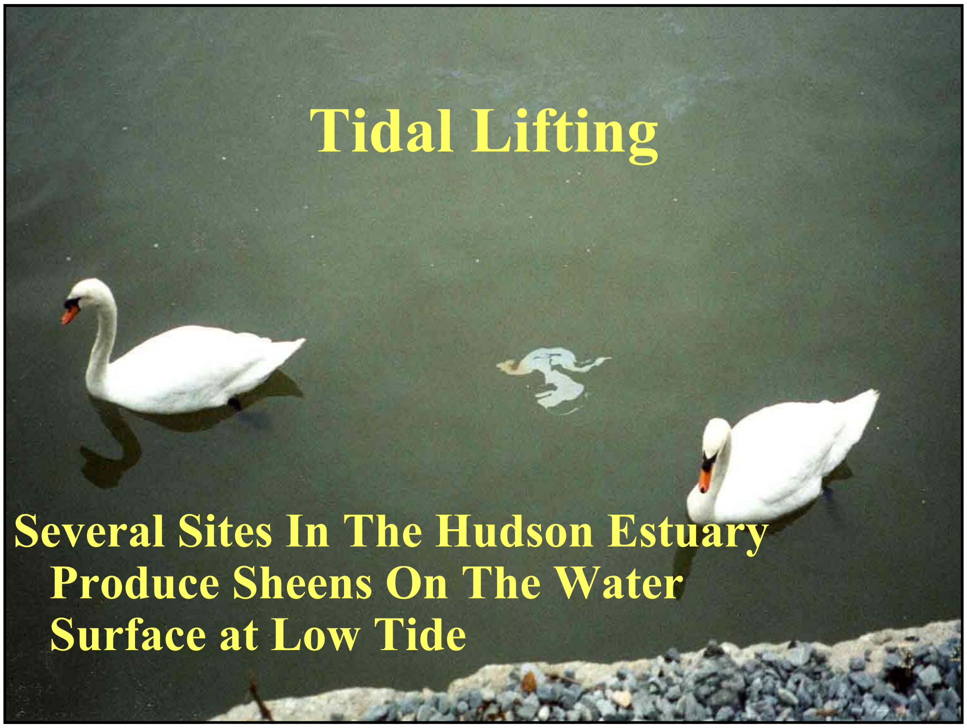

Present-day NAPL Mobility
• What Do We Mean By "Mobile NAPL"
– Bulk Movement Into New Areas
– Induced Movement into Excavations and Wells
– Slow-motion Mobility

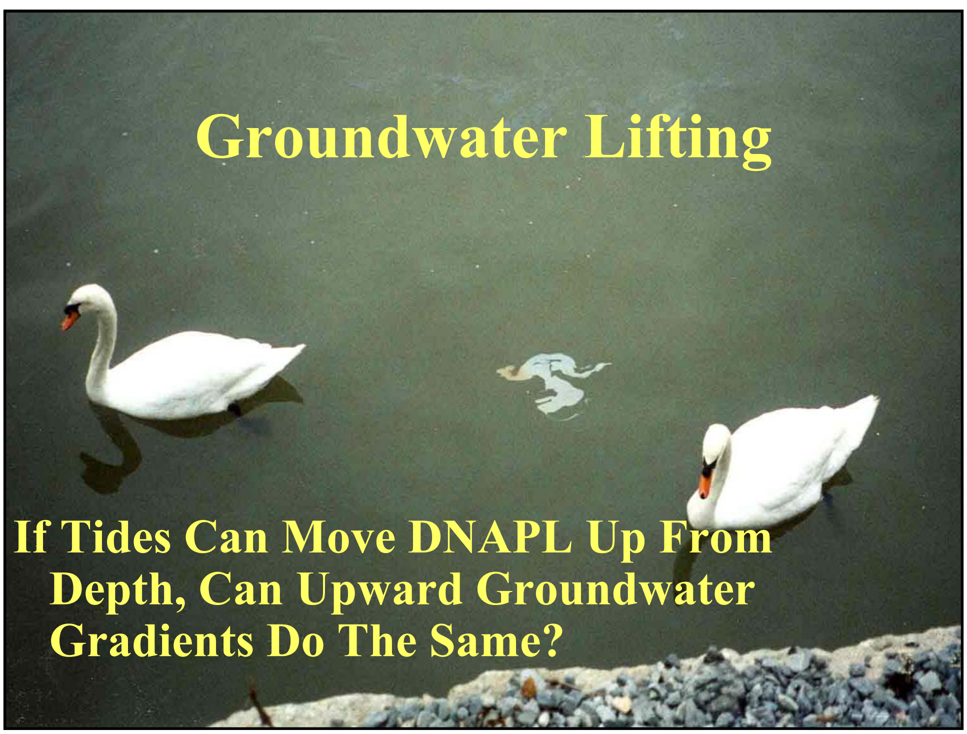

How Do We Know If It's Moving?
• Recontamination of Remediated Areas
• Persistent NAPL Accumulation in Wells
– Delayed Entry Is Common
• Persistent Tar Seeps Into Surface Water
– Variable in Space and Time
• Persistent Tar Boils At Ground Surface


Present-Day NAPL Mobility
• It DOES continue to Move, On Its Own
– Newburgh: Continuing Surface Discharge After 60 Years
– Plattsburgh: Continuing Discharge After 50 Years, and Two Remediations
– Surface Discharges at 16 Other Sites (27 percent of all sites)


Present-Day NAPL Mobility
• The Gastown Example:
– Activities On A Neighboring Property Crucial To Mobilizing DNAPL
• Basement Sump
• Earthen Berm Removal
HOLDER RING


Present-Day NAPL Mobility
Tar Can Be Recoverable At Modest Pumping Rates:
Gastown: 1200 Gallons in 2 Years
Gloversville: Over 4500 Gallons in 3 years
HOLDER RING


Tidal Lifting
Several Sites In The Hudson Estuary Produce Sheens On The Water Surface at Low Tide


Groundwater Lifting
If Tides Can Move DNAPL Up From Depth, Can Upward Groundwater Gradients Do The Same?


Residual Saturation is NOT The Same As "Immobility"
• "Immobilized" NAPL Is Held In Place By a Balance of Dynamic Forces
• This Balance Can Be Upset Easily
– Minor Changes In Groundwater Flow
– Tidal Effects
– Earth Pressure?
– Ground Vibration?


Can The Site Owner Control Mobility?
MGP Sites are Often Small, Urban Parcels
Neigbors Are Close By
Neigboring Land Uses Likely To Be Intense
Excavations
Dewatering
Fill Placement and Vibration
Riverfront Development
HOLDER RING

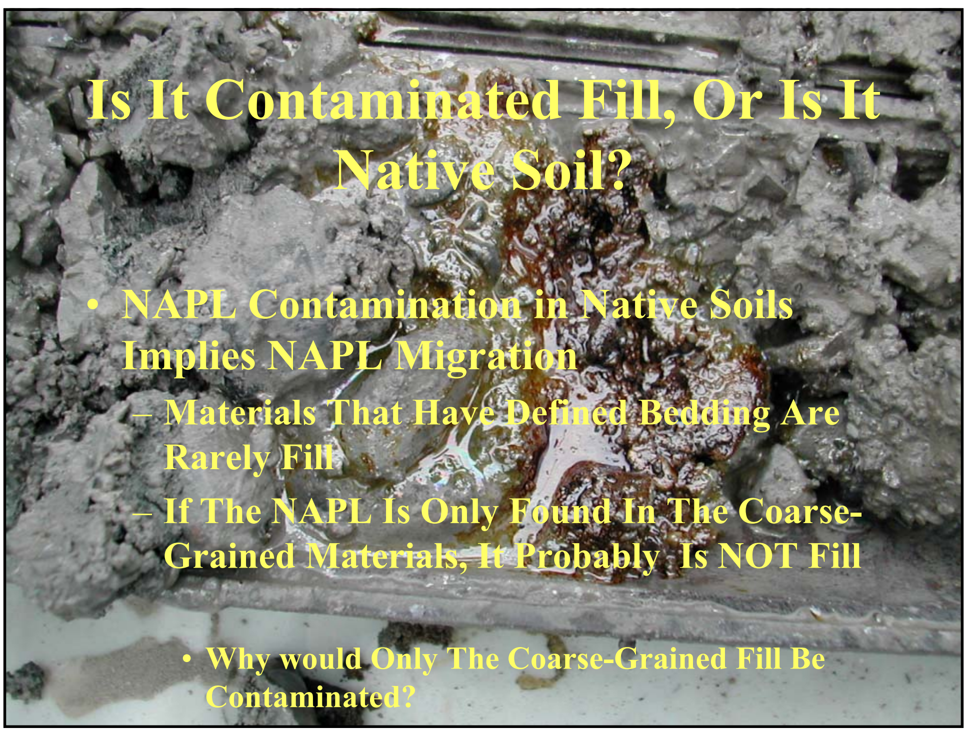

Starting An Investigation?
• Think BIG:
Small Plants Can Impact Large Areas
Old Plants Often Disproportionately Bad


Think SMALL
• Small-scale Geologic Features Often Control Mobility:
– Sand Seams
– Bedrock Joints
– Minor Flaws In Confining Units
• 4 Tar Seams In This Photo Have Moved Over 1200 Gallons of Tar Since 1998


How Reliable Are Your Confining Units?
• Lacustrine Sediments
• Outwash and Overbank Environments
• Tills

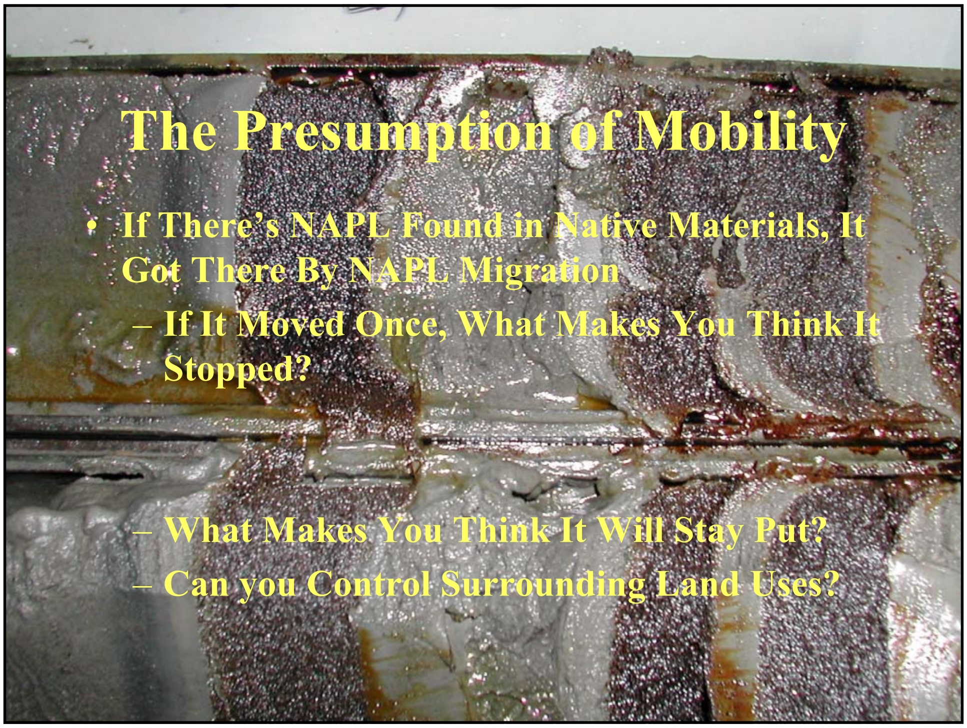

Log Boreholes Carefully
• A Two-Inch Well In The Next Borehole Has Produced Over 4500 Gallons of Tar

DEPTH (FEET)	ELEVATION (FEET)	BLOWS 6"	SAMPLE NO. AND TYPE	PERCENT RECOVERY	PERCENT R.Q.D.	GEOLOGY	CLASSIFI-CATION	DESCRIPTION	REMARKS
	740.0	12 20 22 19	SS #9	100%				Same as above, grey, CGR odor	
17	739.0						SP	Fine sand, poorly graded, 10-20% non-plastic fines, 10-20% medium sand to fine gravel, black, wet, CGR odor	
18	738.0	37 30 17 17	SS #10	25%				Fine sand, poorly graded, 10-20% non-plastic fines, black, distinct CGR odor to 20.5	
19	737.0								
20	736.0	34 50 17 10	SS #11	75%				Fine sand, poorly graded, <10% non-plastic fines, 20-30% coarse sand to fine gravel to 21.5, heavy CGR odor	
21	735.0						ML	[redacted] 10-20% fine sand, black, heavy CGR odor	
22	734.0		SS #12	40%				Same as above, no CGR odor	Refusal with 140 lb hammer, used 300 lb hammer
23	733.0								
24								End of Boring	




Consider Surface Water Transport
• Gross Levels of Sediment Contamination Are Common
• Plattsburgh: NAPL Balls Transported As Sediment For Over 4000 Feet
• Oneida (Sconondoa St): NAPL Transported Over 1000 Feet, Then Reconstituted As A NAPL Plume
• Tidal Effects


Are Sediments Contaminated By Discharge, Or By Subsurface Migration?
• Tar Found Only In Coarse-Grained Units Implies Migration, Not Deposition.


The Presumption of Mobility
• If There's NAPL Found in Native Materials, It Got There By NAPL Migration
– If It Moved Once, What Makes You Think It Stopped?
– What Makes You Think It Will Stay Put?
– Can you Control Surrounding Land Uses?


Thank You

In Situ Thermal NAPL Remediation Technologies

Jim Cummings

Technology Innovation Office

April 2002

1

Scope of Presentation

- Basic Considerations of *In Situ* Treatment
- Fundamental Principles/Processes of *In Situ* Thermal Treatment
- Specific Approaches to *In Situ* Thermal Treatment - Case Studies
- Regulatory and Policy Considerations
- Optimized Remediation Postures

2

Limitations of Extraction-based In Situ Technologies

- Contaminant volatility/solubility/desorption limited at ambient temperatures
- Contaminant recovery often declines asymptotically before remedial goals are met
- Lack of advective flow will occur in some regions of the subsurface
  - » Mass transfer from such regions becomes diffusion-limited and hence very slow

3

Bottom Line

- Pump and Treat is a Protracted Containment Remedy
- ‘O&M’ takes on a whole new dimension for decades/centuries-long projects

4

Mega-/Problem Sites

- **Wood Treaters**
- **Manufactured Gas Plant (MGP) sites**
- **Chlorinated Solvent sites**
- **Drycleaners**
- **Large petroleum hydrocarbon releases (esp. below the water table)**
- **Fractured media**

5

Technical Impracticability Waiver Guidance

"…Sources should be located and treated or removed where feasible and where significant risk reduction will result, regardless of whether EPA has determined that groundwater restoration is technically impracticable…"

Directive 9234.2-25

6

Monitored Natural Attenuation Policy

"…EPA expects that MNA will be **most appropriate when used in conjunction with other remediation measures** (e.g., **source control**, groundwater extraction), or **as a follow up to active remediation measures** that have already been implemented..."

Directive 9200.4-17P

7

Del Amo ROD Excerpt

"…When NAPL is recovered from the ground, its mass and saturation are reduced. In principle, this can (1) **reduce the amount of time** that the containment zone must be maintained, (2) **reduce the potential for NAPL to move** naturally either vertically or laterally, and (3) **increase the long-term certainty** that the remedial action will be protective of human health and remain effective

8

What's New

- Potential to address vadose zone SVOC contamination not amenable to SVE
- Potential to address contamination in the saturated zone below the water table
- Ability to address contamination at depths below those amenable to excavation

9

Good News and Bad News...

- Good tools but not silver bullets
  - » Able to achieve MCL type cleanup objectives in some but not all situations
  - » Greatly accelerate remediation timeframes
  - » May involve significant capital expenditures (but significantly reduced O&M timeframes)

10

General Situation

- ‘Take-off’ phase for simpler solvent sites in the $2-6M range
- Building pressure, but continued RP reluctance to address more costly, complex sites with large quantities of contamination

11

Mechanisms

- Volatilization
- Steam Distillation
- Boiling
- Oxidation
- Pyrolysis
- Viscosity Reduction
- In situ surfactant generation (?)

12

The Visalia Steam Remediation Project

Dynamic Underground Stripping
Of
Creosote and Pentachlorophenol

13

Visalia Pole Yard History

- 1923 -1980 – SCE Operated a Wood Treatment Plant
- **1976 - Groundwater Pumping Was Initiated** – CRWQCB C&A
- 1977 - Grout Wall Completed
- 1985 - Phase 1 Water Treatment Plant
- 1985 - Cal_EPA Superfund Site
- 1987 - Phase 2 Water Treatment Plant
- 1989 - US-EPA Superfund Site – No. 199
- 1992 - RI/FS Completed
- 1994 - RAP/ROD – Enhanced In-Situ Bioremediation
- 1995 - Regulatory Approval For DUS
- 1996 - Design and Construction
- 1997 - DUS Remedial Action

14

Visalia Site Layout

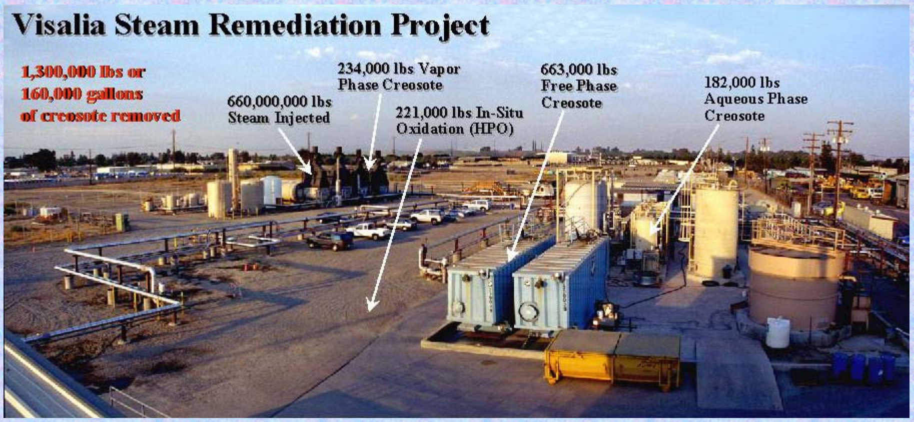
15

What is DUS?

- DUS is a "tool box" of in-situ remedial technologies
  - » ***Steam injection*** to heat the formation
  - » ***Hydrous Pyrolysis Oxidation*** (HPO) to oxidize residual contaminants
  - » ***Electrical Resistance Tomography (ERT)*** for measuring heat distribution
  - » Joule Heating (3-Phase) of low permeability areas
  - » Extraction Systems to recover vapors and liquids

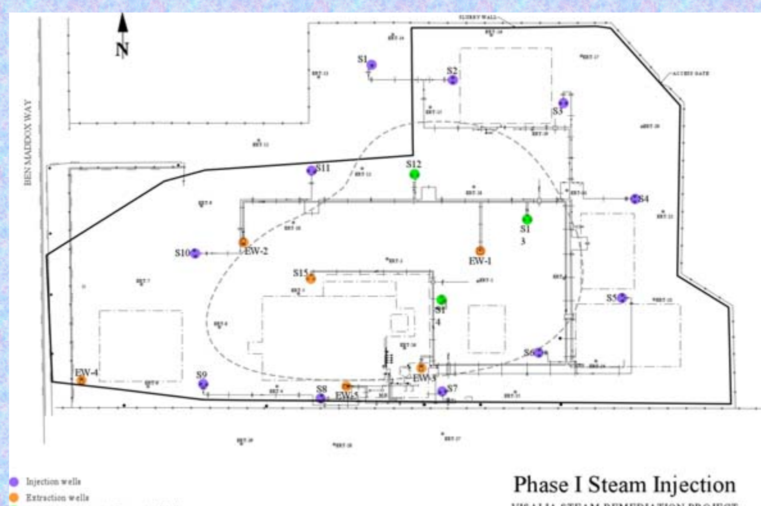
16

Creosote Removed



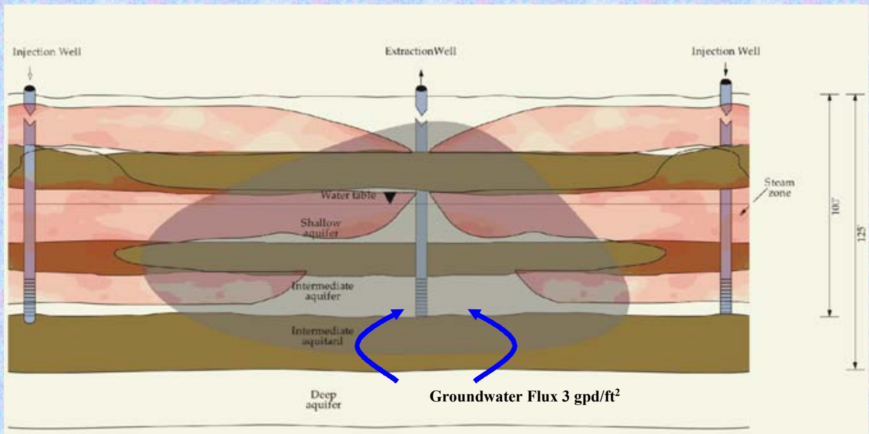
17

Phase I Wellfield Layout



18

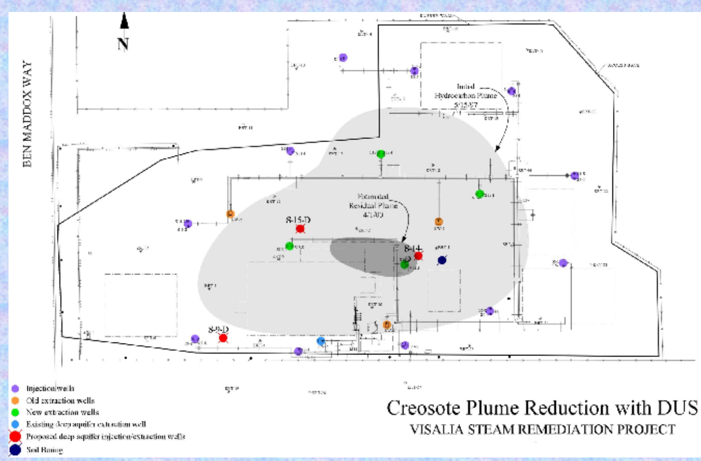
Phase I Steam Injection Cross Section



19

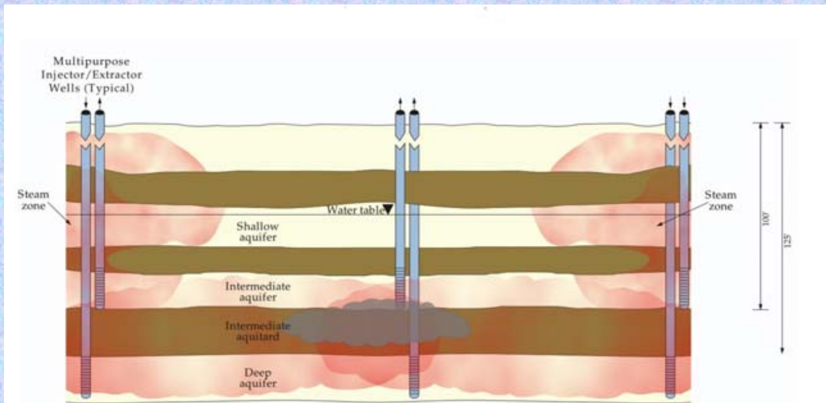
Phase I Results

Creosote Plume Reduction



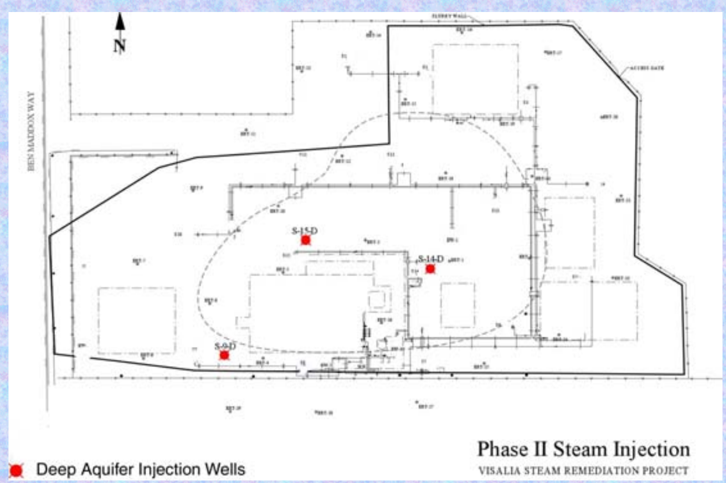
20

Phase II Steam Injection Cross-Section



21

Phase II Deep Well Locations



22

Costs at Visalia

- Total Project Cost - $21.5 million 1996 through 2000
- Unit Cost per Cubic Yard of Soil Treated
  - » Actual Costs $57
  - » With Lessons Learned $38
  - » Solvent and Fuels $25
- Comparative Cost per Gallon of Creosote Removed
  - » Pump and Treat $26,000
  - » DUS $130
- Estimated Time to Remove 1.3 Million Pounds of Creosote
  - » Pump and Treat 3,250 years
  - » DUS 3 years

23

Soil Remediation Using Thermal Enhanced Soil Vapor Extraction

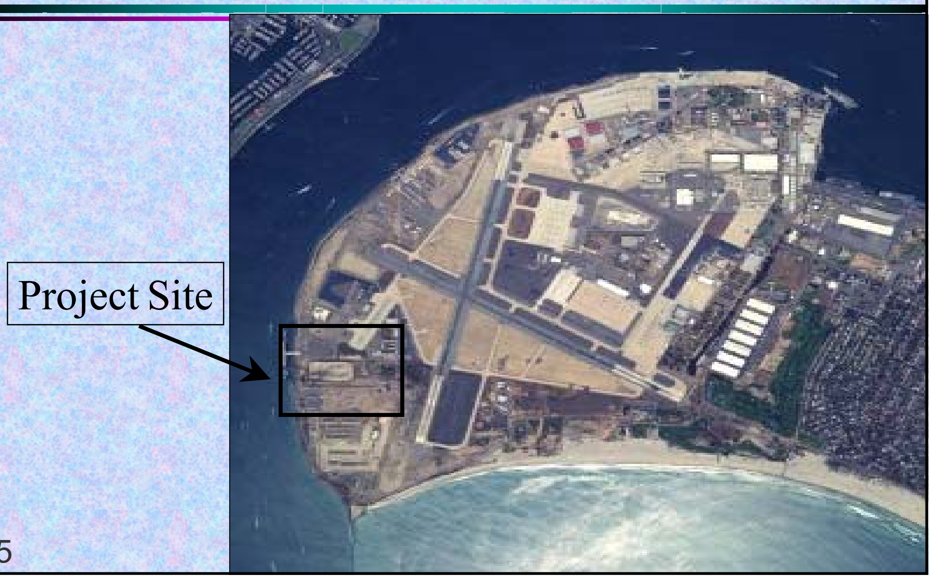
Former Chemical Waste Disposal Area
IR Site 9
Naval Air Station, North Island

Joint ACS/AIChE Session
June 22, 2000
USD, San Diego

OHM Remediation Services Corp

24

Site Vicinity Photo



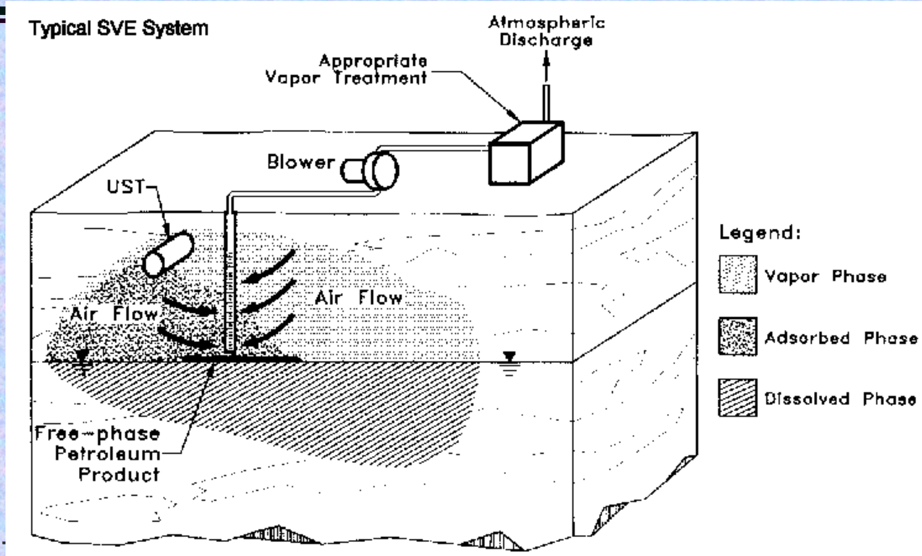
25

IR Site 9 History

- 1940s to 1970s: *estimated* 32 million gallons liquid waste disposed
- Nick-named "the fiery marsh"
  - ✓ Filled during construction of nearby facilities
  - ✓ Currently undeveloped and unused
- 1983: Identified as potential risk to humans and environment
- 1983 to 1994: Site assessments conducted
- 1995: Navy recommended interim action for soil using soil vapor extraction (SVE)

26

Typical SVE System



27

Project Background

- March 1997: 3,000 scfm SVE system initiated
- Objective to REDUCE MASS of volatile organic compounds (VOCs) in soil
- Trichloroethene (TCE) identified as a major risk driver
- Intended as interim action to reduce risk for future full-scale remediation workers
- Groundwater investigations and studies still ongoing

28

3000 SCFM SVE System

29

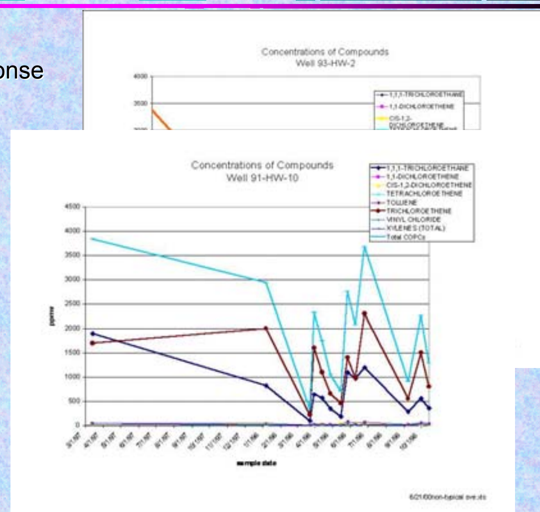
Initial Soil Remediation by SVE

- System operated for 26 months
- Removed over 80,000 pounds of mixed VOCs
- Non-typical SVE response

30

SVE System Response

- Typical SVE System Response

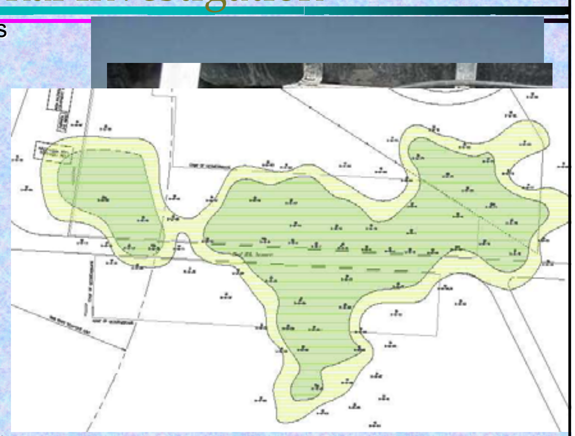


- Site 9 SVE System Response

31

Additional Investigation

- In late1998 Navy Public Works Center (PWC) assisted with investigations



- Free product (JP-5) delineated using Laser Induced Fluorescence (LIF)
- JP-5 commingled with approximately 20 % by weight TCE

32

Additional Investigation Conclusion

SVE Alone Not a Cost Effective Method

33

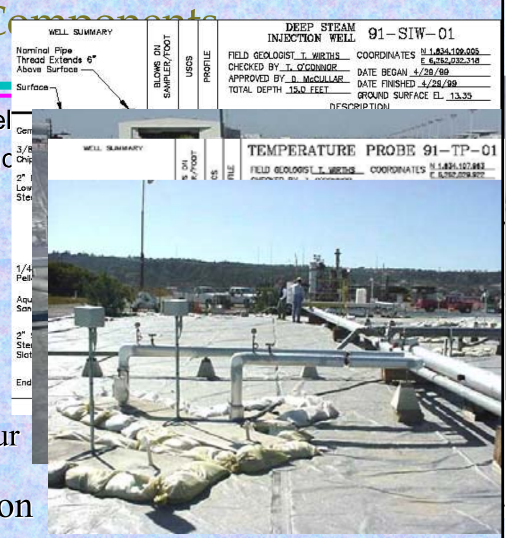
Pilot Scale Thermal Enhancement

- **Evaluated options to *enhance* existing equipment**
  - ✓ **Minimize additional documentation**
  - ✓ **Reduce overall project costs**
- **Thermal enhancement and product skimming**
  - ✓ **Volatilize TCE from free product; capture using SVE**
  - ✓ **Remove free product directly using skimming pumps**
  - ✓ **Increased temperature reduces viscosity and increases flow toward capture wells**

34

System C

- Product Skimming/SVE
  - ✓ 10 Dual Phase Extraction wel
  - ✓ In-well pumps and conveyanc piping
  - ✓ SVE from each well



- Steam Injection
  - ✓3 wells
  - ✓100 to 150 pounds per hour
- Temperature data collection
  - ✓10 sets of 5 nested thermocouples
  - ✓Continuous data logger

35

Thermal Enhanced SVE: Pilot Operation

- September 1999 to May 2000
  - ✓ Over 2000 gallons FP removed via skimming
  - ✓ Over 500 gallons TCE removed via vapor extraction
- Compared to NON-enhanced SVE, thermal enhancement resulted in over 5-times the removal rate
  - ✓ Enhanced: 0.16 pound per month per square foot
  - ✓ SVE: 0.028 pound per month per square foot
- Decision to expand to full-scale

36

Summary

- Thermal enhancement was shown cost-effective for Site 9
- Mass removal increased by more than 5 times over SVE alone
- Proceed to full-scale system: September 2000

37

VOC Remediation Utilizing an Existing On-site Boiler for Steam Enhanced Soil Vapor Extraction

38

Site Background

- Former manufacturing facility in the New England area, operated 1950s – 1997
- VOC Source - releases of styrene and ethylbenzene in a former tank farm area and a containment basin area. Tanks removed in 1998
  - » soil contamination up to 13,000 ppm styrene, 8,500 ppm ethylbenzene
  - » groundwater contamination up to 87 ppm styrene, 43 ppm ethylbenzene, LNAPL reported in past investigations

39

Site Hydrogeology

- Site is located in a river floodplain
- 0-7 feet, fill material in some areas
- 0-28 feet, fine sand and silt with occasional gravel layers and bands of silty clay
- 28-41 feet, coarse to fine sand with traces of gravel or silt
- 41-60 feet, fine sand with traces of silt
- >60 feet bgs — bedrock
- Water table 15-25 feet bgs

40

Remedial Approach

- Thermally-enhanced vapor extraction in vadose zone
- Air sparging in the saturated zone
- Steam injection and vapor extraction screen depths determined by PneuLog™ testing in the field at time of installation
- Two treatment areas, 160’x90’ and 110’x90’ to a depth of 25’
- Conducted bench scale test Dec 1997 to determine feasibility of steam heating

41

System Installation (Oct 99 - Mar 00)

- Former Tank Area
  - Vapor extraction via 10-2” diameter nested SVE wells, screened at 4’-9’ and 12’-17’and 4-4” diameter SVE wells installed for PneuLog™ testing
  - Steam injection via 11 nested steam wells, screened at 5’-8’ and 12-’15’
  - 18 Air sparge wells, 11 of which are nested with the steam wells, screened at 22’-25’
  - 3 temperature thermocouple arrays:
  - 4 nested piezometers screened at 4’-6’ and 8’-11’

42

System Installation (Oct 99 - Mar 00)

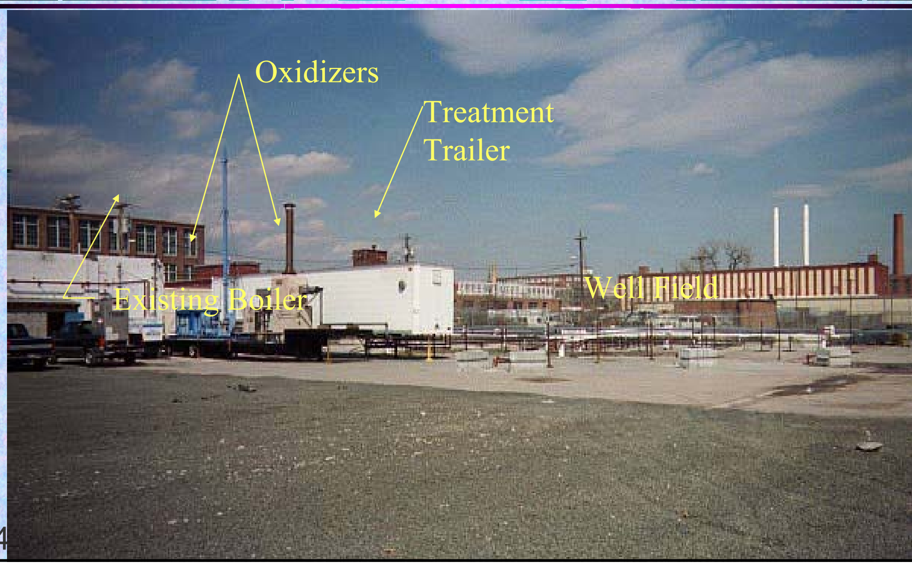
- Former Containment Area
  - » Vapor extraction via 20-2” diameter nested SVE wells, screened at 4’-9’ and 12’-17’and 3-4” diameter SVE wells installed for PneuLog™ testing
  - » Steam injection via 13 nested steam wells, screened at 5’-8’ and 12-’15’
  - » 16 Air sparge wells, 13 of which are nested with the steam wells, screened at 22’-25’
  - » 3 temperature thermocouple arrays
  - » 4 nested piezometers screened at 4’-6’ and 8’-11’

43

Treatment Equipment

- 2 rotary lobe blowers for SVE system (100 hp, 900 scfm@11.5” Hg)
- 1 rotary lobe compressor for AS (25 hp, 225 scfm@14.5 psi)
- Existing boiler (150 hp, 150 psi, 5 MBTU/hr) w/15psi PRV
- 325 gal moisture separator
- 300 gal diffuser tank
- 2-55 gal GAC cannisters
- 2 thermal oxidizers (800 cfm, 600 cfm)

44



4

Cost Summary

- **Design/Fabrication/Installation and Start-up: $850,000**
- **Estimated O & M, 1 year, $180,000**
- **Soil Volume treated based on surface area of wells and depth: 22,500 cy**
- **Cost per cy: $45.80**

46

Thank You

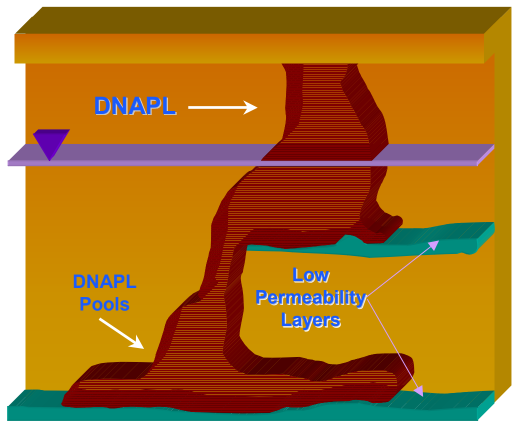
47

Six-Phase Electrical Resistive Heating

What is Six-Phase Heating?

- Takes common 3-phase electrical energy and inputs it to the subsurface through electrodes
- Once in the subsurface, the electrical energy resistively heats soil and groundwater
- Electrodes can be placed vertically to any depth or may be placed horizontally
- Contaminants are removed by direct volatilization and in-situ steam stripping

DNAPL Contamination

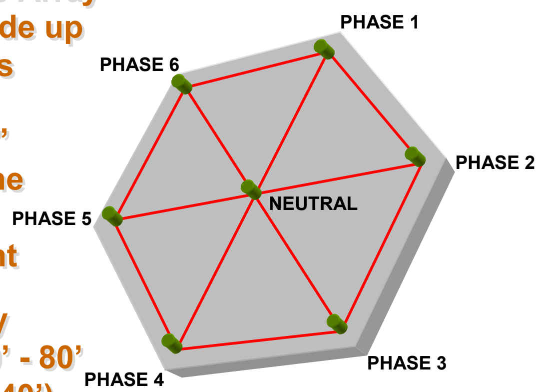


Why Six-Phase Heating?

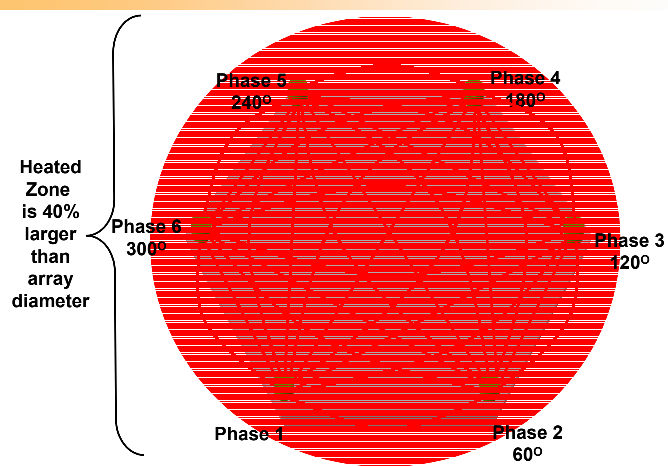
- Heating is uniform, no bypassed regions
- Heating is rapid
- Steam is produced in-situ
- Preferentially heats tight soil lenses and DNAPL hot spots
- Cost effective: $30-$90 per cubic yard

How Does Six-Phase Heating Work ?

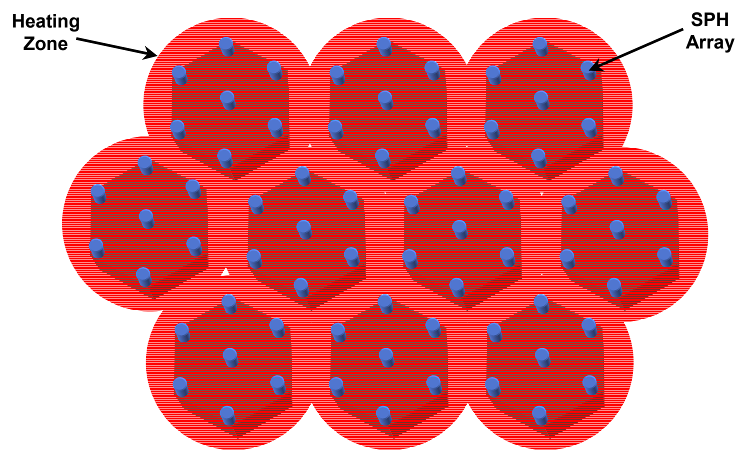
- The Six-Phase Array (SPA™) is made up of 6 electrodes
- A 7th "Neutral" electrode in the center can serve as a vent
- A typical array diameter is 30' - 80' (up from 20' - 40')



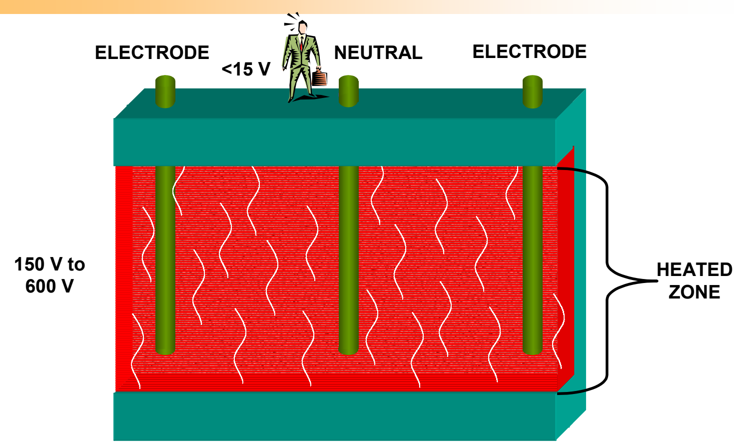
SPH Geometry



Full-Scale Implementation Multiple Arrays



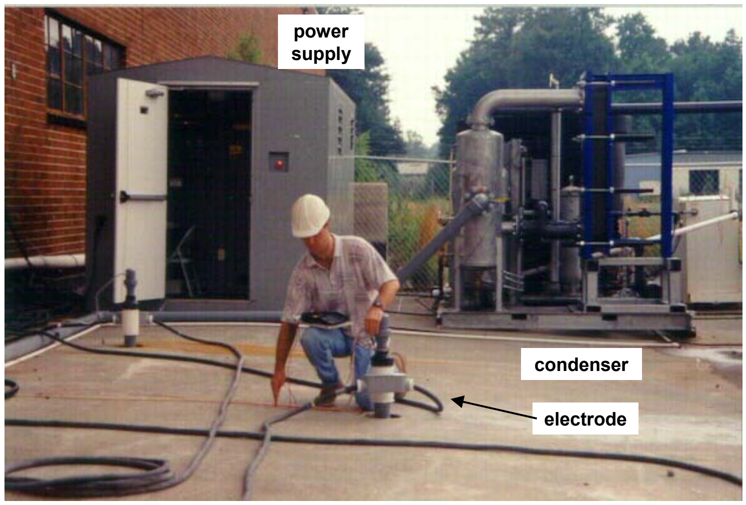
In-Situ Steam Generation



1. Soil grains act as individual resistors

2. Steam generation is uniform through the heated zone

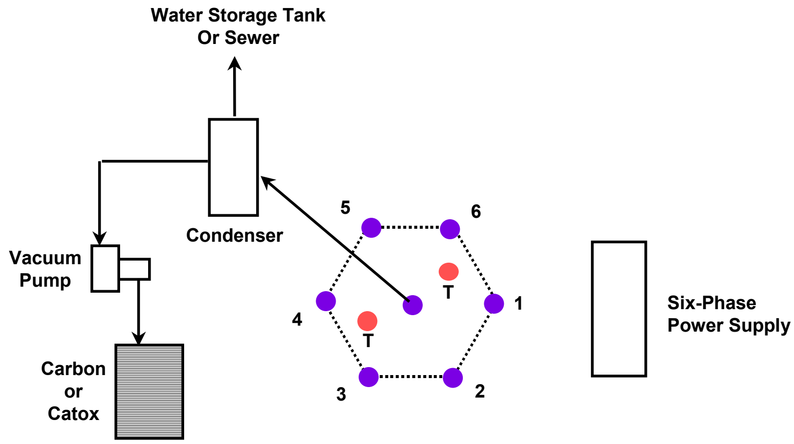
Verifying Safe Voltages



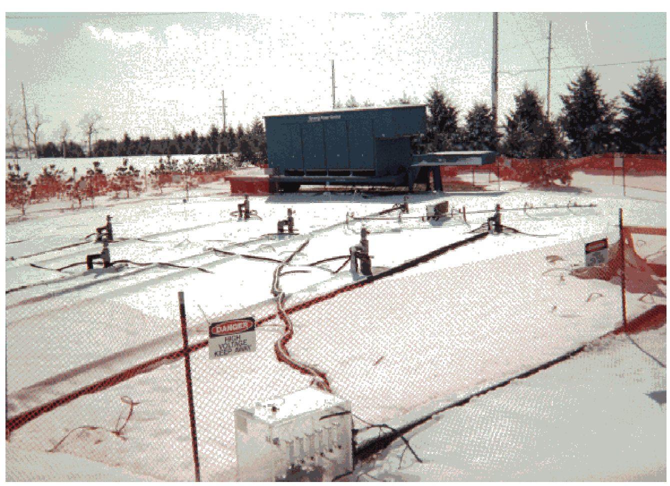
SPH Applications

- DNAPL cleanup by aquifer heating
- LNAPL cleanup by smear zone heating
- Low permeability lithologies
- Heterogeneous lithologies
- Bioremediation enhancement
- Heavy hydrocarbon mobilization
- Rapid remediation

Vapor Recovery System



SPH Power Supply



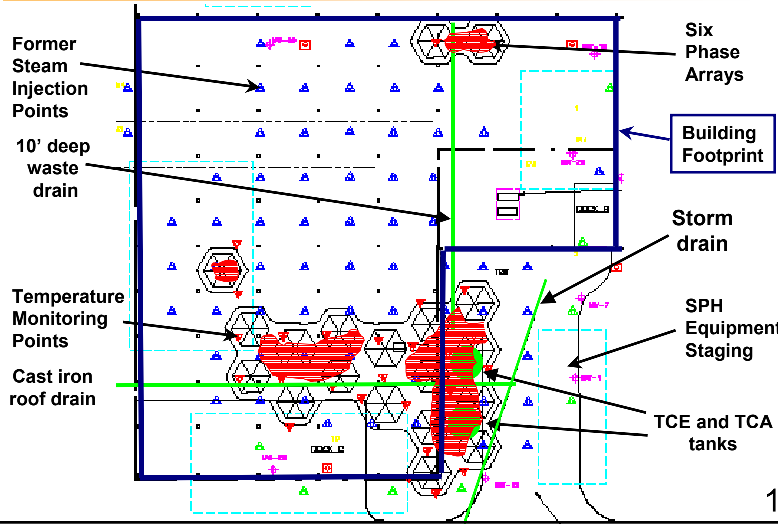
SPH Example Project History

- Savannah River, SC - low perm soil demo
- Dover AFB, DE - DNAPL demo
- Ft. Richardson, AK - recalcitrant VOC demo
- Fort Wainwright, AK - bio/cold region demo
- Skokie, IL - full-scale DNAPL closure
- Cincinnati, OH - LNAPL demo
- Seattle, WA - brownfields cleanup to MCLs
- Atlanta, GA - viscous fuel recovery
- Cape Canaveral, FL - DNAPL "fly-off"

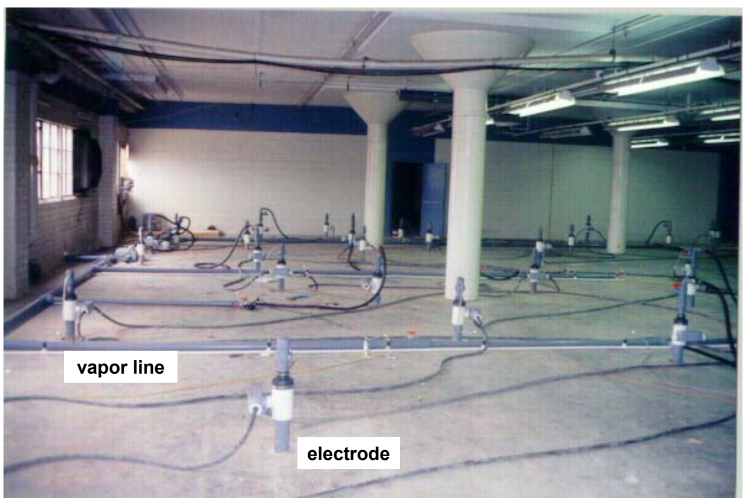
Full-Scale DNAPL Cleanup
The Problem

- DNAPL (TCE & TCA) covering 1 acre of an industrial site
- Steam injection had been applied for 5 years and removed 30,000 pounds of TCE & TCA
- DNAPL pools still remained in four areas, mostly under a large warehouse building
- Goal: Reach Tier III RBCA Cleanup Levels over <u>entire</u> site

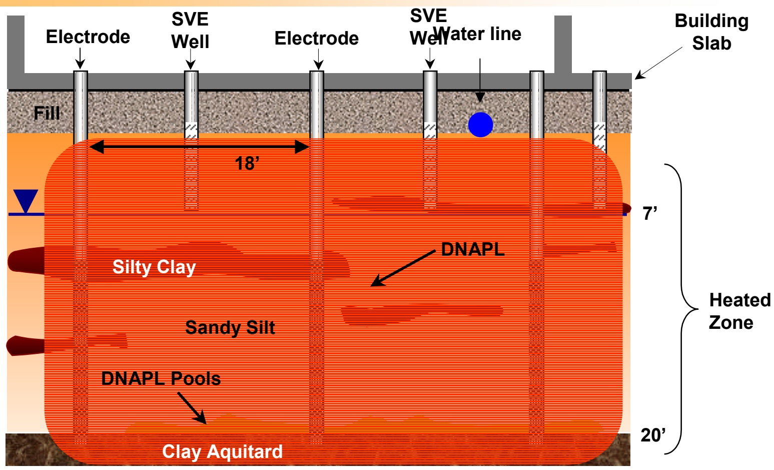
Full-Scale DNAPL Cleanup Site Map



SPH Remediation Beneath a Building



Full-Scale DNAPL Cleanup
Subsurface Cross-Section



Full-Scale DNAPL Cleanup
Operations & Results

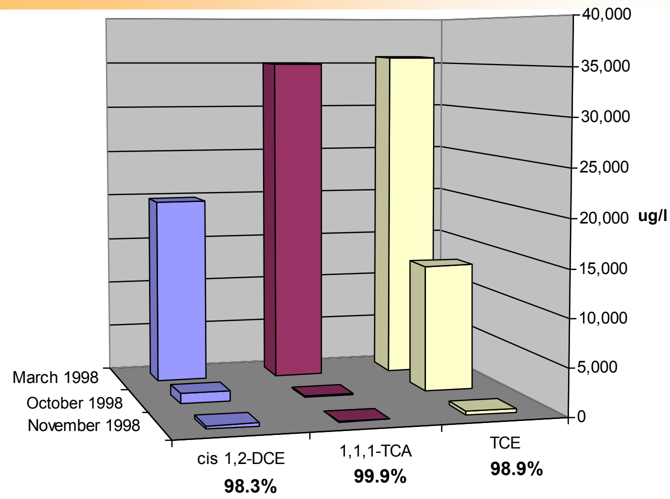
Operations

- Heating (107 electrodes) started June 4
- Aquifer reached boiling in 60 days
- Maintained above the boiling point of TCE (73ºC) for the next 3 months

Results

- Tier III levels by late November 1998; the site is now closed
- >15,000 pounds of VOCs removed

Average Groundwater Concentrations Seven Most Contaminated Wells

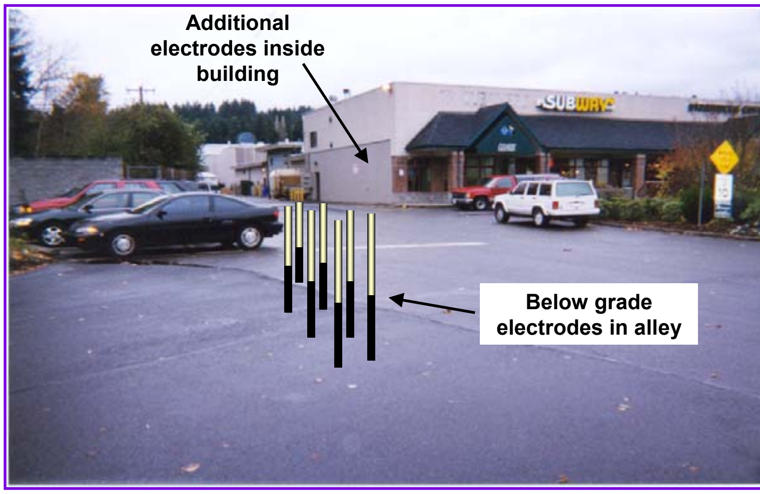


Full Scale DNAPL Cleanup Cost & Performance Data*

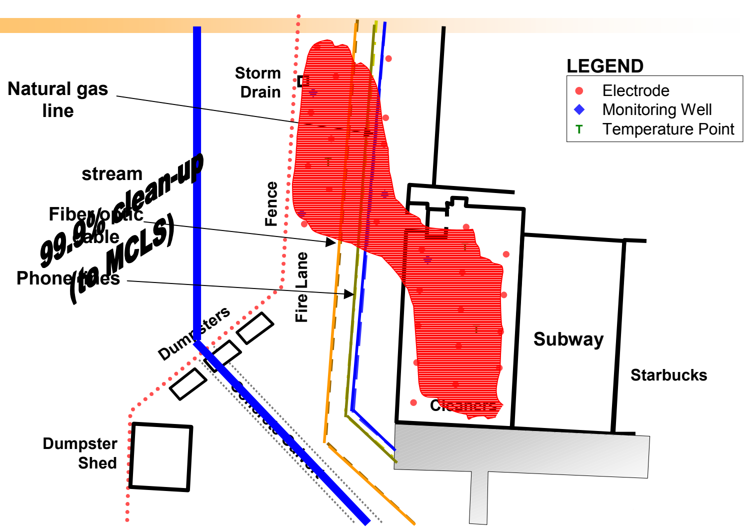
- **Remediation Plan**
  - Remove all DNAPL & Achieve Tier III levels
- **Effectiveness**
  - Total SPH operations took 18 weeks, five days
  - Treated approximately 23,000 cubic yards
  - Since completing SPH, average groundwater VOC concentrations have continued to decrease
- **Costs**
  - Total SPH project costs were $32/cubic yard
  - The total includes electrical costs of $6.50/cubic yard

*The EPA has prepared a third party cost and effectiveness report similar to this data

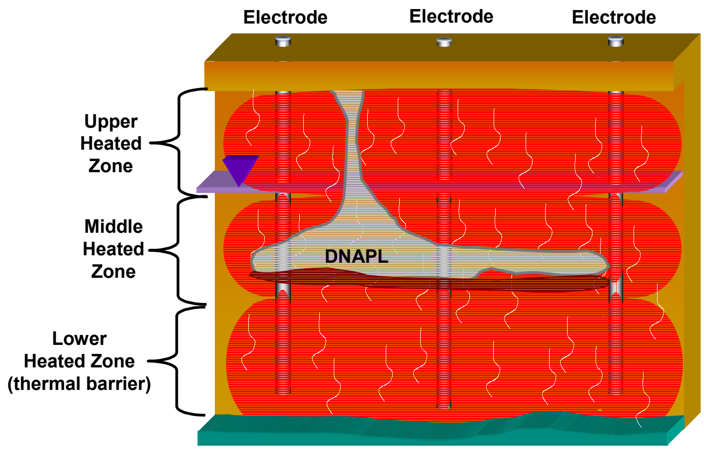
Seattle Remediation to MCLs

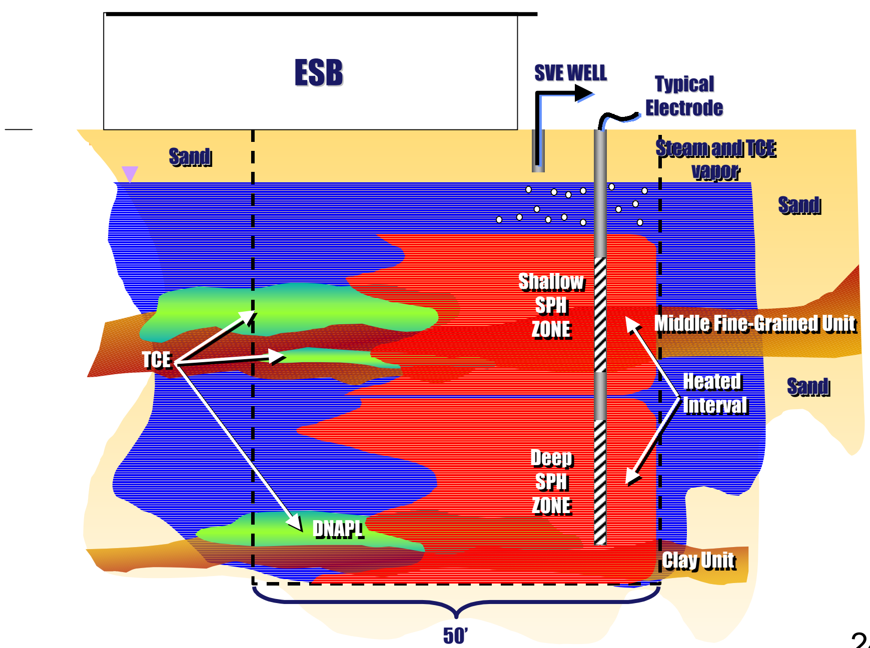


Seattle Remediation to MCLs



SPH Targeted Heating Zones





Six-Phase Heating - Costs

Site	Contam.	Quantity	Cleanup Goal	Unit Cost
Chicago. Ill	PCE	12k yd 40' bgs	75% removal	$80/yd
Skokie, Ill	TCE/TCA	35k yd silt, clay lenses	99% removal	$32/yd
Portland, Oregon	TCE	21,500 yds silt/gravel 65' bgs	99.9% removal	$42/yd
Waukegon	MeCl	16k yd,sand silt.clay 39'bgs	24mg/kg	$61/yd

UPCOMING RESISTIVE HEATING REMOVAL PROJECTS

- **ACTUAL: Lockformer, Ill solvent site**
  - RP Lead
  - R 5 OSC Steve Faryan (312)-353-9351
  - Deployment Spring 2002
- **POTENTIAL: Fargo, ND Drycleaner**
  - RP Lead
  - R 8 OSC: Joyce Ackerman (303) -312-6822
  - Low Permeability Strata – evaluating six-phase heating and in situ oxidation

Thank You

In Situ Thermal Desorption: Remediation of Contaminated Soil by Thermal Conduction and Vacuum

John LaChance

TerraTherm, Inc.

April 2002

TERRATHERM, Inc.

ISTD: Simultaneous Application of Heat and Vacuum

MU-125*

Thermal Blanket

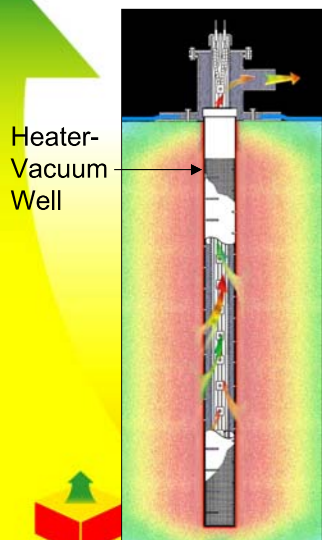
MU-1800*

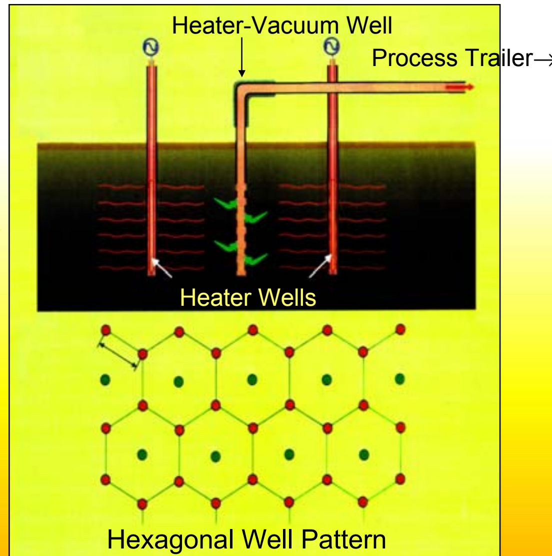
Thermal Wells

TERRATHERM, Inc.

*These units are currently available

ISTD Wells





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Summary of ISTD Process Steps

- Thermal Conduction into Soil
- Vaporization of Fluids within Soil
- In Situ Oxidation and Pyrolysis
  - In-Situ Thermal Destruction
- Collection of Vapors
- Surface Treatment of Vapors

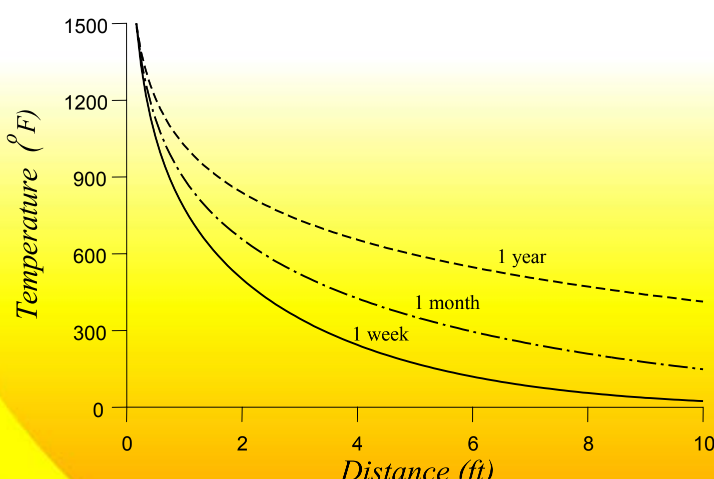
TERRATHERM, Inc.

Thermal Conduction Heating
Unique Characteristics

- Heats Soil Uniformly
  - Vertical Profiles
  - Areal Coverage
- Dries Soil and Creates Permeability
- Attains Very High Soil Temperature (if needed)

TERRATHERM, Inc.

Single Well Temperature Profile



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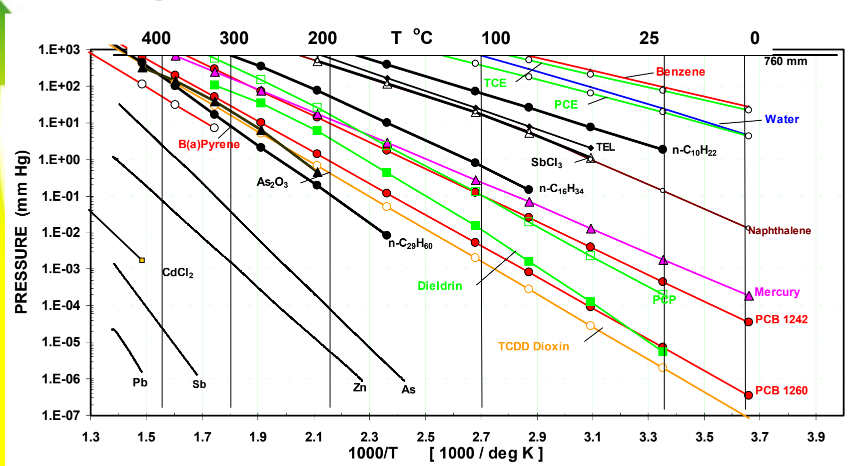
Vapor Pressure of Contaminants



(Stegemeier and Vinegar, 2001)

TERRATHERM, Inc.

Soil Heating Requirements

- Soil
  - Mineral Grains $(1-\Phi)\ \rho_s\ C_s\ \Delta T$
- Water Saturation
  - Sensible $\Phi\ S_w\ \rho_w\ C_w\ \ \Delta T$
  - Latent $\Phi\ S_w\ \rho_w\ h_v$
- Inflow Water
- Air

Where:
Φ = porosity
ρ = density
C = heat capacity
ΔT = change in temperature
S = saturation
h_v = heat of vaporization
s = solids
w = water

Power ≈ 10-30% of overall cost

TERRATHERM, Inc.

Missouri Electric Works (MEW) 12-Well Demo

- Superfund site in Cape Girardeau, MO
- PCBs (Aroclor 1260)
- Boiling Point: 730 - 780 °F
- Depth of contamination: 10 ft.
- Soil Type: Clay
- Maximum Concentration: 20,000 ppm

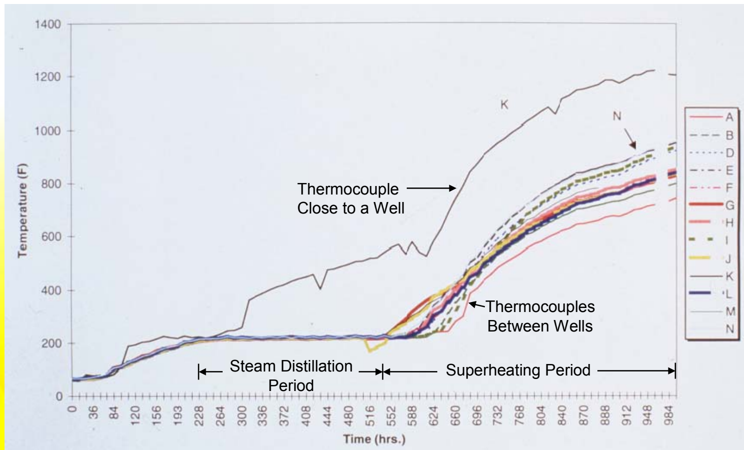
TERRATHERM, Inc.

Results - MEW, Cape Girardeau, MO

- PCBs reduced from about 20,000 ppm to non-detect (<33 ppb) in 76 of 81 soil samples
- Stack testing showed 99.9999998% DRE
- No evidence of contaminant migration
- Dioxins in treated soil below background level (< 6 ppt)

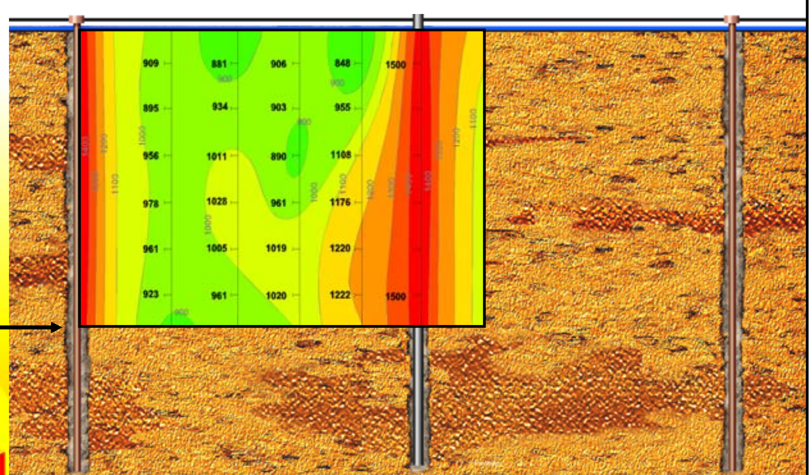
TERRATHERM, Inc.

MEW - Soil Temp. History at 6 Foot Depth



MEW - Measured Temperatures, °F

Vertical Profile Through Well Pattern



8 ft bgs

Summary of Thermal Conduction Field Projects

Location	Contaminant	Initial Concentration (ppm)	Final Concentration (ppm)
Glens Falls, NY	PCB 1248/1254	5,000	< 0.8
Cape Girardeau, MO	PCB 1260	20,000	< 0.033
Mare Is., CA	PCB 1254/1260	2,200	< 0.033
Portland, IN	PCE	3,500	< 0.5
Portland, IN	TCE	79	< 0.02
Tanapag, Saipan	PCB 1254/1260	10,000	< 1
Eugene, OR	Gasoline/Diesel	3,500/9,300 + free product	N.D. benzene; 250,000 lbs. free product removed
Centerville Beach, CA	PCB 1254	800	< 0.17

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(Stegemeier and Vinegar, 2001)

Glens Falls Drag Strip (PCBs)

TERRATHERM, Inc.

ISTD Near Residences, Fuel Depot, Eugene, OR

TERRATHERM, Inc.

Adjacent Residences, Portland, IN

TERRATHERM, Inc.

Significant Hurdles to Treat Sites Contaminated with Chlorinated VOCs

- Must access all subsurface regions affected by CVOCs (DNAPL and/or dissolved source)
  - Drinking water standards many times lower than solubilities (~5 orders of magnitude difference)
  - Without complete removal, dissolved plume will remain >> standards
- Fluid delivery/extraction limited due to heterogeneities
  - Soil permeabilities range over 8 orders of magnitude
  - Soil permeabilities at typical sites in eastern US range over 3 orders of magnitude (e.g., K_h between 10^{-3} to 10^{-6} cm/s)

TERRATHERM, Inc.

Discrete Pathways Reduce Sweep Efficiency of Injected Fluids

Solvent Savers, Linklaen, NY

Smithville, ON

TERRATHERM, Inc.

Advantages of ISTD for Chlorinated Solvents Sites

- Effectiveness is a function of Sweep Efficiency
- Soil thermal properties vary only by a factor of ±2
- Homogeneous and isotropic thermal properties allow accurate simulation of subsurface heating
- ISTD results in very predictable and uniform heating
- 100% Sweep Efficiency of ISTD = unprecedented effectiveness

TERRATHERM, Inc.

TerraTherm's Approach for Chlorinated Solvents Sites

- Gen2 Thermal Conduction Wells at 15' Spacing
- 3:1 Ratio of Heater-Only:Heater-Vacuum Wells
- Attain Steam Distillation Target Temperatures in Centroids between Thermal Wells
  - In-situ destruction will occur in superheated soils in proximity to thermal wells
- Simplified Off-Gas Treatment System:
  - Condenser (if needed);
  - No Oxidizer needed;
  - Dry Scrubber and Carbon Adsorption.

TERRATHERM, Inc.

Upcoming Full-scale Chlorinated Solvent Site

- Confidential Midwest Industrial Facility
  - Voluntary action;
  - 11,500 cy of PCE- and TCE-contaminated soil (low-permeability clay) to 15’ depth; w.t. > 30’;
  - 160 thermal wells over ½ acre;
  - Off-gas treatment: granular activated carbon;
  - Will be treated in one 3-month phase beginning Summer ‘02;
  - Total cost $1.1 M, or $93/cy.

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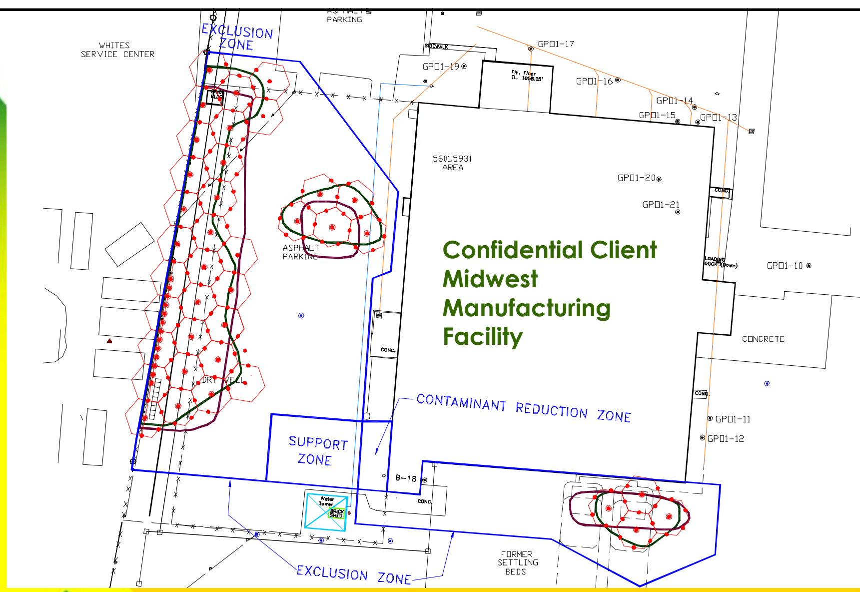

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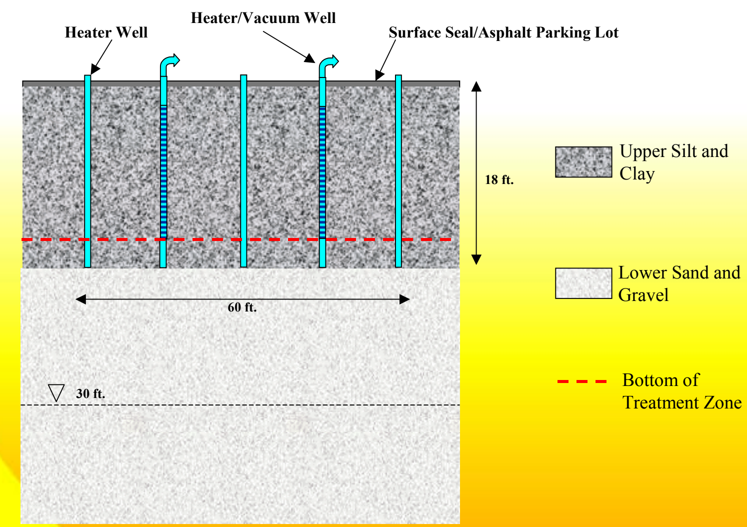
Typical Cross-Section Through ISTD Treatment Zone at Confidential Manufacturing Facility



TERRATHERM, Inc.

Upcoming Full-scale Wood Treating Site

- Former S. Calif. Edison Wood Treatment Facility (pole yard), Alhambra, CA
  - State of CA ERAP site;
  - 14,500 cubic yards (cy) of PAH-contaminated soil to 85' depth (20' avg. depth); w.t. > 200';
  - 835 thermal wells over 0.8 acre;
  - Off-gas treatment: thermal oxidizer + granular activated carbon;
  - Will be treated in two 3-month phases beginning Summer '02;
  - Total cost $5.3M.

TERRATHERM, Inc.

Advantages of ISTD

- Cleans to very low residual levels in situ
- Potential to attain drinking water standards
- Minimal risk of mobilization
- Complete on-site destruction of contaminants
- Broad applicability to volatile, semi-volatile, and non-volatil hydrocarbons
- Process is not hindered by subsurface heterogeneity

TERRATHERM, Inc.

Limitations of ISTD

- Not lowest cost for certain sites (e.g., relative to excavation or capping)
- Water recharge must be controlled for SVOC sites
- Site must be accessible for well installation

TERRATHERM, Inc.

ISTD Price Range

- PCBs, Pesticides, PAHs, Dioxins
  - ~$400/cy for small sites (1000 cy)
  - ~$200/cy for large sites (100,000 cy)
- BTEX, VOCs
  - ~$170/cy for small sites (3000 cy)
  - ~$60/cy for large sites (100,000 cy)
- Price considerations incl.: site access, air discharge limits, need to control recharge, electricity costs, depth of heating zone/length of heaters, regulatory oversight

TERRATHERM, Inc.

About TerraTherm, Inc.

- Founded 2/00
- Univ. of Texas at Austin granted TerraTherm the exclusive, world-wide license to commercialize ISTD technology
  - Protected by 19 U.S. patents, + patents pending
- Offices in Fitchburg, MA and Houston, TX
- For more information, please visit www.terratherm.com

TERRATHERM, Inc.

References

Baker, R.S., and Bierschenk, J.M. 2001. "In-Situ Thermal Destruction Makes Stringent S And Sediment Cleanup Goals Attainable." In: *Proceedings of the Fourth Tri-Serv Environmental Technology Symposium*, 18-20 June 2001, San Diego, CA.

Vinegar, H.J., G.L. Stegemeier, F.G. Carl, J.D. Stevenson, and R.J. Dudley. 1999. "In S Thermal Desorption of Soils Impacted with Chlorinated Solvents." *Proceedings of t Annual Meetings of the Air and Waste Management Association*, Paper No. 99-450.

Stegemeier, G.L., and Vinegar, H.J. 2001. "Thermal Conduction Heating for In-S Thermal Desorption of Soils." Ch. 4.6-1 in: Chang H. Oh (ed.), *Hazardous a Radioactive Waste Treatment Technologies Handbook*, CRC Press, Boca Raton, FL.

Thank You

Summary/Conclusions

- Promising New Tools to Achieve Environmental Remediation/Facility Restoration Objectives
- "Brave New World": Link Aggressive Source Term Remedies with Cost Effective Polishing Approaches for Residual Plume
  - e.g., potential to reduce mass flux to allow credible, reasonable timeframe MNA

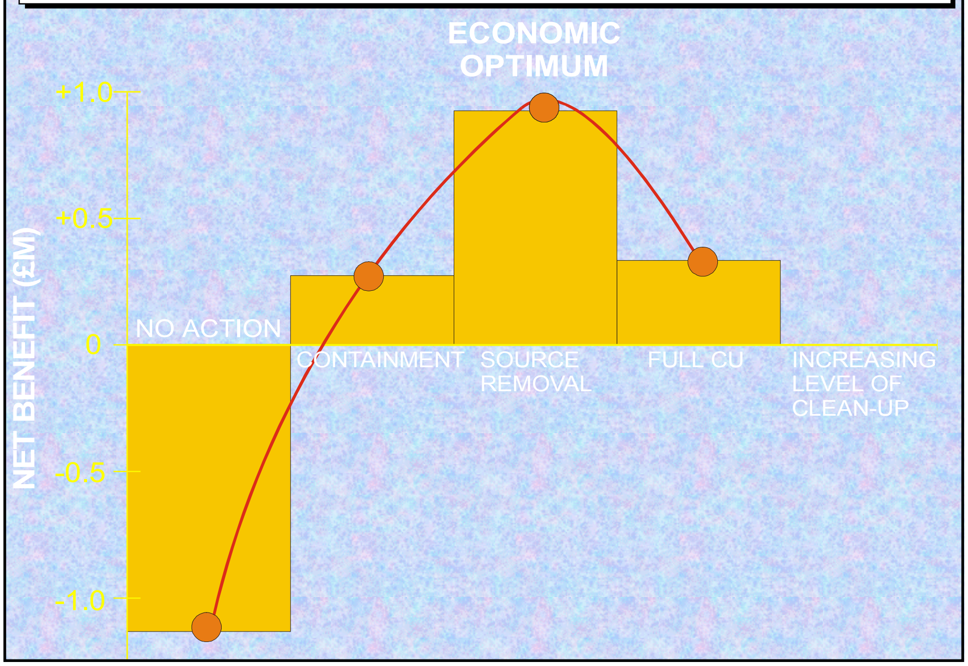
The "$64,000 Question"

- Can you remove enough mass to allow meaningful risk reduction and meaningful reduction in Pump and Treat/MNA timeframes
- At 'many' sites - Yes
- At 'most' sites - ?

Next Steps (One among many…)

- **Develop Regulatory Framework which rewards good behavior and provides <u>certainty</u> to parties conducting remedial activities**
  - **<u>Worst</u> fear: Turn on expensive remedy, won't be able to turn it off**
  - **<u>Second worst</u> fear : Protracted pump and treat even after source term remedy**

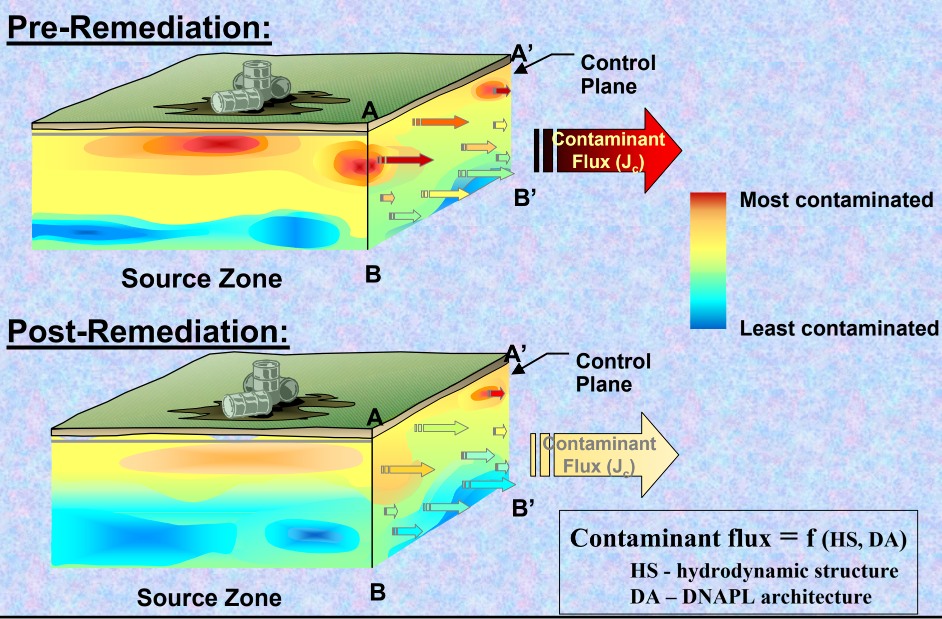
BENEFITS ASSESSMENT FOR REMEDIAL GOAL SE



Desired End State/Least Cost Solutions

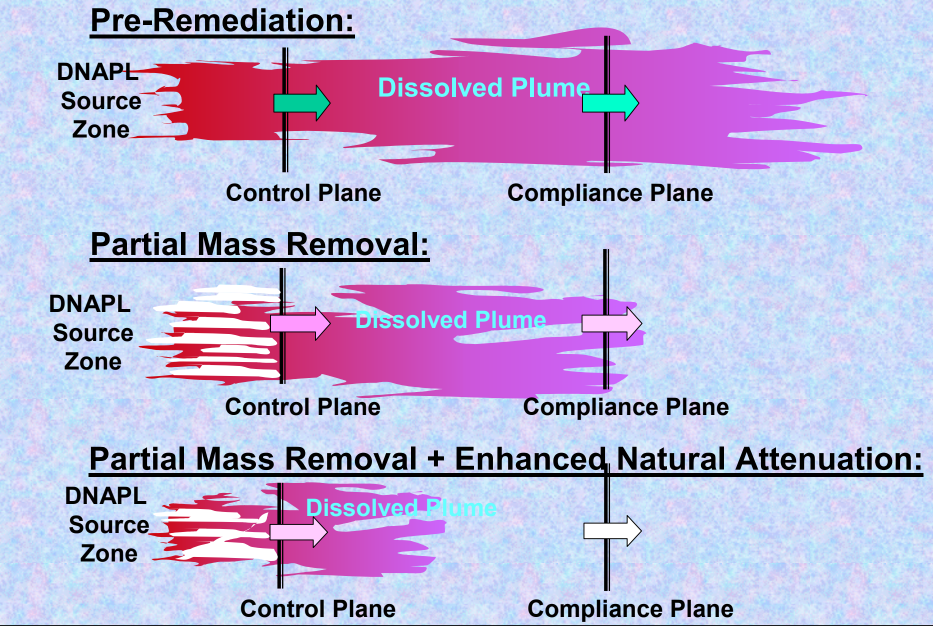
- Adequate Use of Robust Source Term Removal Technologies
- Timely transition to cost-effective 'polishing' step(s)
- Reduce/Eliminate Need for Pump and Treat
- Appropriate Reliance on MNA

Mass Reduction vs Mass Flux



Contaminant flux = f (HS, DA)
HS - hydrodynamic structure
DA – DNAPL architecture

PLUME RESPONSE



Contact Information

- Jim Cummings, TIO/OSWER
  - 703-603-7197
  - Cummings.james@epa.gov
  -

- In Situ Thermal Information
  - Cluin.org/products/thermal
  - Cluin.org/thermal

Thank You